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THE NEPHELITE SYENITE AND NEPHELITE PORPHYRY OF BEEMERVILLE, NEW JERSEY

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INTRODUCTION

During the earlier geological survey of New Jersey many outcrops of igneous rocks, mainly dykes, were mapped and recorded in the state reports without particular description. These rocks are nearly all located in Sussex County, and, owing to the small size of most of the outcrops, their scattered nature, the maturity of the topography, and the extent of weathering of the rocks themselves, their interesting nature has only been recognized gradually, though the first record of the largest mass dates back to 1868.

Through the work of Emerson, Kemp, and Wolff these rocks are now widely known and are regarded in the local sense as a suite of genetically connected alkalic intrusions, and more generally as

showing affinity with the rocks of a dominantly sodic zone or comagmatic region which finds expression in the eastern United States from New England to Texas.[1]

The large mass of nephelite syenite situated to the northwest of Beemerville was first described in detail by Emerson, who recognized its true character and described it microscopically. He believed the mass to be a large dyke.[2] Emerson also described, under the name of mica-diabase, the series of dykes penetrating the ore-bodies at the Buckwheat Field at Franklin Furnace.[3]

Kemp examined the mass known as Rutan's Hill, which forms a prominent landmark east of the northern end of the main mass of nephelite syenite at Beemerville, and described it as a boss of porphyrite, giving two analyses of the rock, and one of the biotite isolated from it.[4] He also recognized the nature of a number of similar "bosses" to the southeast of the main mass, south of Beemerville and Plumbstock. On a more detailed investigation Kemp mapped and described the main mass and its immediate satellites, demonstrating clearly the inhomogeneity of the Beemerville nephelite syenite and proving the occurrence of a nephelite porphyry, probably as a dyke, within it. Here also he showed that the satellitic bosses are basic alkalic rocks, allied to the ouachitites and fourchites. He provided two analyses of different facies of the nephelite syenite and one of the nephelite porphyry.[5] These investigations established the fact that the Beemerville mass and its associates resemble the rocks of the Magnet Cove complex, Arkansas.

Kemp next examined a basic dyke two miles northwest of Hamburg, and from microscopical investigation, and the analysis of certain pseudomorphous spheroids which it exhibited, he offered the tentative suggestion that the rock was a leucite tephrite, and concluded that it was related to the Beemerville nephelite syenite.[6]

[1] H. S. Washington, *Jour. Franklin Inst.*, CXC (1920), p. 796.

[2] B. K. Emerson, *Amer. Jour. Sci.*, XXIII (1882), p. 302.

[3] *Ibid.*, p. 376.

[4] J. F. Kemp, *Amer. Jour. Sci.*, XXXVIII (1889), p. 130.

[5] J. F. Kemp, *Trans. N.Y. Acad. Sci.*, XI (1892), p. 60.

[6] J. F. Kemp, *Amer. Jour. Sci.*, XLV (1893), p. 303.

Kemp's material was studied by Hussak, who had no hesitation in terming the rock a leucite tephrite, and considered that the spheroidal pseudomorphs were pseudoleucite, or were at any rate pseudomorphs after leucite.[1] Kemp then visited some newly exposed dykes at Rudeville and obtained material which provided definite proof of the existence of leucite, and came to the conclusion that the "mica-diabase" dykes of Rudeville, Franklin Furnace, and the Hamburg dyke are all related to the Beemerville mass.[2] Kemp's papers are illustrated with useful locality maps, but the analyses given are all incomplete and inadequate.

A complete petrological description of the nephelite syenite of Beemerville and the large dyke at Franklin Furnace, together with good, though incomplete, analyses, is given by Iddings, who recognized the Franklin Furnace dyke to be a minette.[3]

In 1899 Ransome described a small occurrence of nephelite syenite, mica syenite, hornblende syenite, and hornblende granite, associated with Mesozoic gabbro, at Brookville, in Hunterdon County, New Jersey, sixty miles west of south from Beemerville. The relations of these rocks to the gabbro were not clearly ascertained, and they were regarded by Ransome as inclusions, though he considered the possibility of an intrusive relation.[4] Our colleague, Dr. N. L. Bowen, has collected specimens from this locality which suggest differentiation of the nephelite syenite and, on a small scale, an intrusive relation toward the gabbro.

In 1902 Wolff described an undoubted leucite tinguaite dyke, which cuts the Beemerville nephelite syenite mass near its southern end, giving a detailed account of the pseudoleucite, and a good and complete analysis of the rock. This is the most satisfactory existing analysis of any rock from the alkalic series of Sussex County.[5] Finally, in 1908 Wolff provided a co-ordinated description of the igneous rocks of Sussex County,[6] in which he points out that the same

[1] E. Hussak, *Neues Jahrbuch*, II (1892), p. 153.

[2] J. F. Kemp, *Amer. Jour. Sci.*, XLVII (1894), p. 339.

[3] J. P. Iddings, *U.S. Geol. Surv., Bull. 150* (1898), pp. 209 and 236.

[4] F. L. Ransome, *Amer. Jour. Sci.*, VIII (1899), p. 417.

[5] J. E. Wolff, *Bull. Mus. Comp. Zoöl. Harvard*, XXXVIII (1902), p. 273.

[6] J. E. Wolff, *Geol. Atlas, New Jersey*, Franklin Furnace folio (1908), p. 12.

pyroxene, a zoned aegirite-augite, and large crystals of titanite and biotite characterize nearly all the rocks of the series, and that the main nephelite syenite mass of Beemerville, with its transgressive dykes of nephelite porphyry and leucite tinguaite, has a definite relation to the disposition of other rocks of the series. Close to it, to the east and south, are the bosslike or necklike ouachitite breccias; farther to the southeast is a zone of nephelite syenite and bostonite dykes, which, like the main mass, are concordant with the bedding of the intruded series (the Ordovician Martinsburg shale); finally, at some distance to the southeast, are the lamprophyric dykes, which are disposed radially toward the Beemerville mass, intruding the Ordovician Kittatinny limestone and the pre-Cambrian Franklin limestone. Wolff concludes that the alkalic rocks are post-Devonian in age and probably much later.

THE NEPHELITE SYENITE OF THE BEEMERVILLE MASS

The main mass of nephelite syenite forms a long, narrow intrusion of elliptical outcrop, lying between the Silurian Shawangunk conglomerate and the Ordovician Martinsburg shale, at the foot of the Kittatinny Ridge, the southern extremity of the mass being two miles to the northwest of Beemerville. It is most easily accessible from the town of Sussex (formerly called Deckertown, and referred to by that name by Emerson and Kemp).

The formal relationships of the mass are obscure. Both Emerson and Kemp regarded it as a large dyke, but Wolff is inclined to regard it as a sill, or an irregular, flat laccolithic mass. Washington visited the locality in 1901 in company with Professors Kemp and Brögger, and is in agreement with Wolff's opinion. It was examined by Aurousseau in the summer of 1921, with special regard to this point, but no evidence of a decisive nature is obtainable on the ground. As the mass has been studied by a number of competent geologists at intervals over a long period of time, it is improbable that any fuller information will be forthcoming, the outcrops being poor and the contacts obscured by thick soil and drift. In particular, no variations of dip are to be observed in the massive Shawangunk conglomerate which overlies the mass. To our minds the occurrence of the body (which can hardly be younger than

early Tertiary and is probably much older) at the junction of the Shawangunk conglomerate and the Martinsburg shale, is critical, and, taken in conjunction with the fact that long, narrow intrusions of nephelite syenite and bostonite lie parallel to the bedding of the Martinsburg shale farther to the east, inclines us to the opinion that the Beemerville mass is a lenticular sill, or a flat laccolith.

The nephelite syenite is a somewhat basic foyaite, of the "foyaite range" as recently defined in the classification of the nephelite syenite family proposed by Shand.[1] It is very variable along the mass and, although the bulk of the exposure is a fairly constant foyaite of the Magnet Cove, Arkansas, or the Umptek type, it grades locally into other facies, which are often more basic than the main mass. Ditroitic and ijolitic modifications may be collected, and especially along the eastern border it becomes foliated, or lujavritic, in character. Near the center of the exposure, small, local facies with abundant titanite may be found. These variations have been admirably described by Emerson and by Kemp. Kemp's description may be quoted to illustrate this point:

> The dike varies considerably along its course. The typical elaeolite-syenite forms the northern third and the southern extremity, but between these points its character changes. Near the southern part of the middle third elaeolite-porphyry appears, and forms a most beautiful example of this rock. It may come from dikes, as no actual exposures are available. Further south a basic holocrystalline rock comes in which is exposed in place; and, as subsequently shown, contains less silica and more biotite than the typical syenite. But on the extreme south where the highway crosses the dike, the rock is much like that on the north. It is, however, greatly decomposed, and fresh, firm, pieces are hard to find.[2]

The variation, even of what appears to be the predominant rock, is well shown by comparing the analyses by Eakins and Aurousseau (Table I). The Martinsburg shale, along the eastern contact, has been metamorphosed to a hornstone, the aureole being narrow.

To the very complete petrographic description of the normal rock, given by Iddings, we have little to add. One slight correction is necessary. The mineral identified as sodalite belongs to the hauynite-noselite series, as is indicated by the analysis here given.

[1] S. J. Shand, *Trans. Geol. Soc. South Africa*, XXIV (1921), p. 117.

[2] J. F. Kemp, *Trans. N.Y. Acad. Sci.*, XI (1892), p. 64.

The most noteworthy chemical characters of the nephelite syenite are its low silica percentage, the approximate equality in amount of soda and potash, the high content of titanium and zirconium, and the comparatively large amount of SO_3 as compared with chlorine. Though it undoubtedly belongs to the highly sodic

TABLE I

	I	II	III	IV	V	
SiO_2	47.19	53.56	53.09	52.25	Z	0.18
Al_2O_3	23.01	24.43	21.16	22.24	Or	33.08
Fe_2O_3	3.11	2.19	1.89	2.42	An	6.39
FeO	2.23	1.22	2.04	1.98	Lc	11.99
MgO	1.07	0.31	0.32	0.96	Ne	32.66
CaO	2.93	1.24	3.30	1.54	Th	0.71
Na_2O	7.97	6.48	6.86	9.78	Nc	0.95
K_2O	8.23	9.50	8.42	6.13	Di	4.32
H_2O+	0.55	0.93	1.13	0.73	Ol	0.98
H_2O-	0.04		0.24		Mt	1.39
CO_2	0.38	.....	0.82	.....	Il	4.10
TiO_2	2.16	.....	0.11	0.60	Hm	2.08
ZrO_2	0.13	.....	0.04	.....	Ap	1.01
P_2O_5	0.39	.....	0.15	0.53	Water	0.59
SO_3	0.45	.....	None	.....	.....	.....
Cl	0.01	.....	0.02	.....	.....	.....
F	p.n.d.	.....	.....	.....	.....	.....
S	.....	.....	0.08	.....	.....	.....
Cr_2O_3	None	.....	.....	.....	.....	.....
$(CeY)_2O_3$	0.06	.....	.....	.....	.....	.....
MnO	0.16	0.10	0.20	.....	.....	.....
BaO	0.09	.....	0.61	.....	.....	.....
Sum	100.16	99.96	100.48	99.16	.....	100.43

I. Nephelite syenite, Beemerville, N.J. M. Aurousseau, anal.

II. Nephelite syenite, Beemerville, N.J. L. G. Eakins, anal. *U.S. Geol. Surv. Bull. 150* (1898), p. 211.

III. Foyaite, Magnet Cove, Ark. H. S. Washington, anal. *Jour. Geol.*, IX (1901), p. 611.

IV. Lujavrite, Rabots Spitze, Kola. V. Hackmann, anal. *Fennia*, XI (1894), p. 132.

V. Norm of I. Symbols, (I) II. 7. 1′. 3. Janeirose.

comagmatic region of the eastern United States, in these respects it differs remarkably from the well-known nephelite syenites of Massachusetts, Connecticut, New Hampshire, and Maine, and also from the nearest similar exposure, that is, from the nephelite syenite of Brookville. The last-named rock resembles the nephelite syenites of New England and shows the essential differences between them and the Beemerville rock (see Table III). The other nephelite syenites of the northeastern United States, and, in

general, those of eastern Canada, are characteristically dosodic, contain less titanium, and where it has been determined, less zirconium than that of Beemerville: they are also more silicic, and some of the Canadian rocks have a marked tendency to show an excess of alumina. The material analyzed by Eakins is termed "the average rock" by Iddings. That used for the analysis here presented was

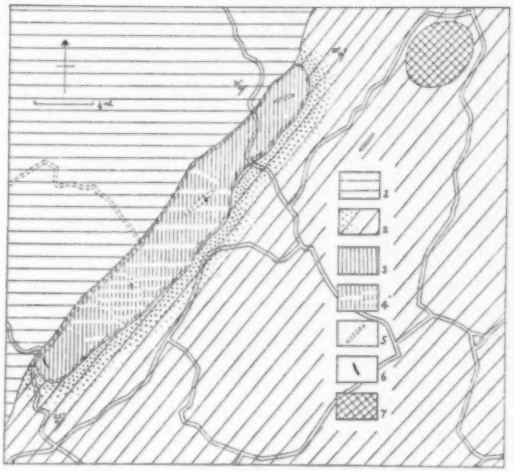

FIG. 1.—The *character* of the Beemerville intrusion, as inferred from the distribution of rock types: (1) Shawangunk conglomerate. (2) Martinsburg shale and contact aureole. (3) Normal nephelite syenite, with occasional nepheline-rich, and lujavritic (marginal) facies. (4) Transition of normal nephelite syenite into darker variety with biotite and titanite. (5) Nephelite porphyry, with tinguaitic and sussexitic facies. (6) Leucite tinguaite. (7) Ouachitite breccia of Rutan's Hill. Diagram partly idealized. Main boundaries from the Franklin Furnace folio. The probable occurrence of a dyke of nephelite porphyry in the northern part of the main mass is suggested by an observation of Emerson, *Amer. Jour. Sci.*, XXIII (1882), p. 308.

collected by Dr. Wolff and is representative of the northern third and the southern extremity of the mass. The non-determination of TiO_2 and P_2O_5 by Eakins of course affects the figures for Al_2O_3.

As has been stated already, the Beemerville nephelite syenite resembles most closely the foyaite of Magnet Cove, Arkansas. An analysis of the latter rock is given in Table I for comparison together with a lujavrite from Umptek, described by Hackmann. The Arkansas rocks are characteristically sodi-potassic, like those

of the Beemerville, though slightly more silicic. The most noteworthy differences are in the titanium and zirconium, and in the ferrous-ferric relationships. The Arkansas syenite apparently contains less of the acmite and more of the diopside molecule than that of Beemerville, and is distinctly poorer in titanium and zirconium. The minor differences among the volatile constituents also are not without interest.

THE NEPHELITE PORPHYRY

The nephelite porphyry, referred to in Kemp's description of the variations of the main mass, is not exposed in a way which permits of a determination of its relationships. It is found in the neighborhood of Mr. T. Conroy's house, near the middle of the main mass, and specimens have been collected from the north of the house, and from the peach orchard southwest of the house. Again quoting from Kemp:

> At the middle of point 4 C on the map the character of the dike changes, as is indicated by the float fragments, for no actual exposures occur. Porphyritic facies appear, and an excellent elaeolite porphyry was found. . . . . Another porphyritic rock occurs along this portion of the dike, which lacks the large phenocrysts of elaeolite. It has, however, others of feldspar, and in the slide shows the same tinguaitic base with a much more prismatic development of the elaeolite in the groundmass.[1]

A small dyke of the same rock occurs two miles northwest of the town of Sussex, and is shown on the map of the Franklin Furnace folio. The nephelite porphyry of the main mass of Beemerville does not reveal its contacts. We believe it to be a dyke of some size, intruding the main mass, and both coarse- (definitely porphyritic) and fine-grained modifications, the latter suggestive of marginal relationship, may be collected north of Mr. Conroy's house.

The rock is typically porphyritic with nephelite crystals, and occasionally with orthoclase. In one specimen small phenocrysts of blue fluorite are quite visible to the naked eye. The groundmass, which has the typical, dull-green color of the tinguaites, is variable in texture in different specimens, and in the finer-grained variety consists of a mosaic of interlocking grains of orthoclase and nephelite, penetrated by minute aegirites. In the more normal variety the aegirites exist in two generations, those of the groundmass forming

[1] J. F. Kemp, *Trans. N.Y. Acad. Sci.*, XI (1892), pp. 66–67.

minute tufts. Orthoclase also shows its twinned development here. The larger aegirites are associated with small but numerous crystals of titanite and a little biotite. A few patches of ilmenite are noticeable, and under high power a little perovskite and apatite may be seen. Cancrinite and hauynite are quite minor constituents, and there is very little development of carbonates. The general mineralogical development is quite similar, except as regards texture, to that of the nephelite syenite itself. Though orthoclase exists in minor amount in some cases, ordinarily it is an important constituent.

TABLE II

	I	II	III	IV	V	VI	VII	VIII	
SiO_2	50.08	49.84	49.96	55.31	45.64	50.16	46.48	Z	0.32
Al_2O_3	17.64	19.47	19.23	21.74	19.50	19.75	19.00	Or	41.14
Fe_2O_3	4.70	4.40	4.55	1.77	3.47	4.28	4.74	Ab	4.19
FeO	2.27	2.24	2.26	1.02	3.34	3.62	2.30	Ne	30.10
MgO	1.12	1.34	1.23	0.47	3.04	1.12	2.49	Hl	0.12
CaO	3.96	4.35	4.15	1.57	4.45	3.10	4.35	Th	0.71
Na_2O	8.10	8.07	8.08	8.77	11.57	7.63	8.46	Nc	0.32
K_2O	7.30	6.71	7.01	6.49	6.96	6.73	6.78	Ac	3.70
H_2O+	.....	0.38	0.38	1.94	0.16	3.96	3.31	Di	6.70
H_2O-	0.06	.....	0.06						
CO_2	.....	0.12	0.12	0.11	.....	.....	0.36	Wo	3.71
TiO_2	1.75	1.27	1.51	0.07	2.44	.....	1.22	Mt	3.48
ZrO_2	.....	0.16	0.16	.....	.....	.....	.....	Il	2.89
P_2O_5	0.54	.....	0.54	Tr.	.....	0.13	0.15	Hm	0.80
SO_3	0.39	.....	0.39	.....	.....	.....	0.19	Ap	1.34
Cl	.....	0.04	0.04	0.60	.....	.....	0.08	Water	0.44
F	.....	.....	p.n.d.	.....	.....	.....	.....	.....	.....
Cr_2O_3	.....	None	None	.....	.....	.....	.....	.....	.....
$(CeY)_2O_3$	.....	0.05	0.05	.....	.....	.....	.....	.....	.....
MnO	0.17	.....	0.17	.....	0.19	.....	Tr.	.....	.....
BaO	0.32	.....	0.32	.....	.....	.....	.....	.....	.....
Sum	.....	.....	100.21	99.86	100.76	100.48	99.91	.....	99.96
Less O	.....	.....	0.01	0.13	.....	.....	0.02	.....	.....
Sum	.....	.....	100.20	99.73	100.76	100.48	99.89	.....	.....

I. Nephelite porphyry, Beemerville, N.J. H. S. Washington, anal. Incomplete.
II. Nephelite porphyry, Beemerville, N.J. M. Aurousseau, anal. Incomplete.
III. Average(excluding Al_2O_3 of I) of I and II.
IV. Tinguaite, Monte Mulatto, Predazzo, Tyrol. M. Dittrich, anal. J. Romberg, *Sitzb. Preuss. Akad. Wiss.*, I (1902), p. 748.
V. Nephelite porphyry, Wudjavrtschorr, Upmtek, Kola. V. Hackmann, anal. V. Hackmann, *Fennia*, XI (1894), p. 151.
VI. Tinguaite, Hooper's Inlet, Dunedin, New Zealand. P. Marshall, anal. P. Marshall, *Quar. Jour. Geol. Soc.*, XLII (1906), p. 396.
VII. Leucitite, Etinde Volcano, Kamerun. M. Dittrich, anal. *Sitzb. Preuss. Akad. Wiss.* (1901), p. 299.
VIII. Norm of III. Symbols, II. (6) 7. 1. 3. Janeirose.

Chemically the rock is a foyaite and differs in no essential manner from the nephelite syenite. Indeed, the similarity of the analyses of the nephelite syenite and of the nephelite porphyry is remarkably striking. The latter contains less alumina and titanium than the former, but is a very close parallel to it otherwise. What has been said, therefore, of the affinities of the nephelite syenite applies likewise to the nephelite porphyry. The specimen analyzed was selected with care, and comes from the neighborhood of the peach orchard mentioned. It is, as nearly as possible, the average porphyry.

The rock was analyzed independently by each of us. As the summation from Washington's figures was low, and inspection showed that the figures for alumina were probably at fault, the average of the two analyses was taken, excluding the alumina from I, and correcting that of II only by the deduction from it of one-half of the difference between the two determinations of TiO_2. Column III represents the accepted values. On comparing the rock with others of a similar nature, it is seen that it resembles the nephelite porphyries of other localities. In particular may be mentioned the nephelite porphyry of Julianehaab[1] (Fox Bay type), which is very different mineralogically, however, and the nephelite syenite porphyry of the Val dei Coccoletti, in the Tyrol.[2] The last-named rock is practically the chemical equivalent of the tinguaite of Monte Mulatto, Predazzo, and indeed, so great is the chemical resemblance of the Beemerville nephelite porphyry to certain tinguaitic and leucitic rocks, that we quote the tinguaite of Monte Mulatto (IV of Table II) in preference to the nephelite porphyry. Column V is the nephelite porphyry of Umptek, a more sodic rock, but otherwise similar; while VI and VII are respectively the tinguaite of Hooper's Inlet, Dunedin, New Zealand, and a leucitite from Kamerun. The similarity in chemical composition between the Beemerville magma and the magma which has produced the richly leucitic leucite phonolite of Poggio Muratella, Lake Bracciano, has already been pointed out elsewhere.[3] We desire to stress the simi-

[1] N. V. Ussing, *Geol. Julianehaab, Meddel. om Grönld.*, XXXVIII (1911), p. 275.

[2] J. Romberg, *Sitzb., Preuss. Akad. Wiss.*, I (1911), p. 748.

[3] H. S. Washington, *The Roman Comagmatic Region* (1906), p. 47.

larity of the nephelite porphyry of Beemerville to other nephelite porphyries and similar rocks, because the Beemerville rock, on the basis of a poor analysis, was made the type of the species sussexite. This matter will be discussed below.

CRYSTALLIZATION VARIANTS OF THE BEEMERVILLE MAGMA

The nephelite porphyry and the leucite tinguaite described by Wolff occur within the main mass of nephelite syenite. We believe the first to be a dyke of some magnitude, while the second is a dyke only fifteen inches wide. The leucite tinguaite, also, differs from the nephelite syenite in no other way than in the reversal of the ferrous-ferric relation and a change in the rôle of sulphur (see II of Table III below). The main mass crystallized completely as orthoclase, nephelite, and aegirite. The smaller mass (dyke?) of nephelite porphyry is only a textural variant of the same magma, while the smallest dyke, of the same chemical composition, is a mineralogical variant, having produced a certain amount of leucite and little or no primary orthoclase. The symbols of the three rocks indicate clearly that there has been no chemical differentiation. They are as follows:

Nephelite syenite, Beemerville, (I) II.7.1′.3.
Nephelite porphyry, Beemerville, II.(6)7.1.3. } Janeirose
Leucite tinguaite, Beemerville, II.7(8).1.3.

They all fall in the same subrang. It may be mentioned here that the subrang Beemerose was established from Eakin's analysis, which does not seem to be so representative of the mass as the new analysis here presented. The crystallization variants appear to be due to differences in the rates of cooling of the three rocks, an assumption based upon the respective volumes of the masses concerned. That a nephelite syenite magma is capable of producing leucitic rock is a matter of great interest, and the presence of nearly 12 per cent of leucite in the norm of the Beemerville nephelite syenite may be significant in this respect. The great similarity of the Beemerville magma to certain tinguaites, as already mentioned, is a matter of like nature, that is, the expression of magmas of similar composition in feldspathic and feldspathoid form. In view of some results obtained by Morey and Bowen, on the thermal

relations of leucite and orthoclase,[1] there is no difficulty in accepting the leucite tinguaite of Beemerville as the rapidly cooled equivalent of the nephelite syenite. This interpretation also tends to confirm Kemp's diagnosis of leucite in the true differentiates of the magma, the dykes at Rudeville and Hamburg.

THE OCCURRENCE OF ZIRCONIA AND RARE EARTHS

In the Beemerville rocks the amount of zirconia is rather high. This illustrates the fact that the region east of the Appalachians, from Essex County Massachusetts, through New Jersey as far as North Carolina, and possibly beyond, is a region rich in zirconia. Numerous localities for zircon have been discovered in New Jersey (personal communication from Dr. J. E. Wolff), and its distribution, and that of the rare earths in places, is so well known in Virginia and North Carolina as to need no great comment here. The zirconia is not necessarily confined to sodic rocks, and indeed most frequently occurs in zircon pegmatites, like the well-known pegmatite at Tuxedo, near Hendersonville, North Carolina. The rare earths occur mostly in allanite, which has a fairly wide distribution in Maryland and Virginia. Our determination of the rare earths in the nephelite syenite and nephelite porphyry is the first record of them in northern New Jersey. A number of unpublished analyses of aegirites, by Washington, indicate that the rare earths of the Beemerville rocks occur in the aegirite. The bulk of the rare earth precipitates in our analyses was too small to admit of any separation being made, but the chemical behavior during the determinations suggests that yttrium preponderates over cerium, and that thorium is present.

As the literature of the alkalic rocks of northern New Jersey is scattered, and in part somewhat old, we append the superior analyses of other rocks of the district, with which we have not dealt directly here. We have included an inferior analysis of the ouachitite of Rutan's Hill, by Kemp, as there is no other chemical information extant concerning the basic lamprophyres. The summation of this analysis is low, in spite of the fact that the iron is all expressed as Fe_2O_3, and the water and CO_2 are merely repre-

[1] G. W. Morey and N. L. Bowen, *Amer. Jour. Sci.*, IV (1922), p. 1.

sented as "loss on ignition." As regards the other analyses of the table, the MnO of II is probably too high, and the non-determination of P_2O_5 and TiO_2 in III of course render the figures for alumina too high. All other analyses of the alkalic igneous rocks from this region we have discarded as unfit for use.

TABLE III

	I	II	III	IV
SiO_2	54.68	50.00	40.71	40.47
Al_2O_3	21.63	20.03	19.46	11.86
Fe_2O_3	2.22	0.98	7.46	17.44
FeO	2.00	3.98	6.83	
MgO	1.25	0.69	6.21	3.10
CaO	2.86	3.41	11.83	16.80
Na_2O	7.03	8.28	1.80	1.90
K_2O	4.58	8.44	3.26	4.21
H_2O+	1.88	1.50	1.53	3.60
H_2O-	0.27	0.10		
CO_2	None	0.22	0.74	.....
TiO_2	0.79	0.99	.....	.....
P_2O_5	0.28	0.21	.....	.....
SO_3	0.07	.....	.....	.....
Cl	None	Tr.	.....	.....
F	0.22	n.d.	.....	.....
FeS_2	.....	0.54	.....	.....
MnO	Tr.	0.50	0.18	.....
BaO	0.05	None	.....	.....
Sum	99.81	99.87	100.01	99.38
Less O	0.09	.....	.....	.....
Sum	99.72	99.87	100.01	99.38

I. Nephelite syenite, Brookville, Hunterdon Co., N.J. G. Steiger, anal. *Amer. Jour. Sci.*, VIII (1899), p. 423.

II. Leucite tinguaite, Beemerville, N.J. J. E. Wolff, anal. *Bull. Mus. Comp. Zoöl. Harvard*, XXXVIII (1902), p. 276.

III. Minette, Franklin Furnace, N.J. L. G. Eakins, anal. *U.S. Geol. Surv. Bull. 150* (1898), p. 238.

IV. Ouachitite, Rutan's Hill, Beemerville, N.J. J. F. Kemp, anal. *Amer. Jour. Sci.*, XXXVIII (1889), p. 133.

THE STATUS OF SUSSEXITE

Brögger, in working out the grorudite-tinguaite suite of the Kristianiagebiet, extrapolated from his analyses of the series, and calculated an end member for the suite, the composition of which is shown in column II of Table IV. No rock corresponding to this hypothetical composition was found in the Kristianiagebiet,

but Brögger considered that Kemp's analysis of the Beemerville nephelite porphyry, together with the description, indicated that a rock of the hypothetical, calculated composition, and corresponding to an end member of this series, actually existed. He therefore defined the species now known as *sussexite*,[1] making the Beemerville rock the type, in the following terms:

> Gesteine wie diejenigen von Beemerville waren aber früher nur wenige bekannt, jedenfalls nur wenige analysirt; sie bilden einen ganz distincten chemischen Typus, wie sie auch geognostisch durch ihre häufige Verknüpfung mit Nephelinsyeniten charakterisirt sind; dementsprechend sind sie reich an Alkalien, arm an Kalk und Magnesia und mässig reich an Eisenoxyden, aber mit sehr hohem Al_2O_3 Gehalt. Es wäre entschieden irreleitend, diese Gesteine als Nephelinite zu bezeichnen, nur deshalb weil sie aus Nephelin (und Aegirin) bestehen.

A sussexite, according to Brögger's definition, is a nephelite porphyry either poor or lacking in orthoclase, and therefore a persodic or dosodic rock, resembling the urtites and ijolites in composition.

TABLE IV

	I	II	III
SiO_2	45.18	45.0	47.43
Al_2O_3	23.31	25.0	23.60
Fe_2O_3	6.11	6.5	4.59
FeO			1.20
MgO	1.45	1.5	1.20
CaO	4.62	2.0	0.67
Na_2O	11.16	12.0	15.08
K_2O	5.95	7.0	2.00
H_2O	1.14	1.0	.....
TiO_2	.....	.....	0.10
Sum	98.92	100.0	99.09

I. Nephelinitic facies of nephelite porphyry, Beemerville, N.J. J. F. Kemp, anal.(?) J. F. Kemp, *Trans. N.Y. Acad. Sci.*, XI (1892), p. 67. Brögger's type for the species Sussexite.

II. Hypothetical Sussexite, calculated by extrapolation from the Grorudite-Tinguaite series. W. C. Brögger, *Eruptivgest. des Kristianiagebietes*, I (1894), p. 172.

III. Sussexite, Penikkavaara, Kuusamo, Finland. M. Dittrich, anal. V. Hackmann, *Bull. Comm. Géol. Finlande*, XI (1900), p. 22.

Kemp's analysis (see I of Table IV) indicates that the sample he analyzed corresponded fairly closely to Brögger's definition of

[1] W. C. Brögger, *Eruptivgest. des Kristianiageb.*, I (1894), p. 173.

the type. It is certainly dosodic. We have shown here that the nephelite porphyry of Beemerville is a sodipotassic rock, in no important respect different from other nephelite porphyries, and we can only conclude that the sample chosen for analysis by Kemp was not representative. Kemp's own descriptions of the nephelite porphyry show that the rock he described was not abnormally poor in orthoclase. Consequently the Beemerville rock cannot maintain its position as the type sussexite. Only one rock corresponding to Brögger's original definition has been analyzed so far, it being the sussexite of Kuusamo, Finland, described by Hackmann (see III of Table IV). As it establishes the existence of the species (the existence of which may be said to have been predicted by Brögger), the name sussexite should remain in use, in the sense of Brögger's definition. Sussexite is essentially a nephelite porphyry devoid of feldspar, or, in other words, a porphyritic urtite.

Rocks of the nephelite syenite family tend to lack homogeneity within the mass, and too much care cannot be exercised in the selection of material for analysis, which will correspond well with the material upon which the petrographic descriptions are based. Another instance showing lack of correspondence between the chemical analysis and the mineralogical description is the mariupolite described by Morozewicz.[1] The analysis of this rock does not permit of the existence of the amount of nephelite it is said to contain (according to the description).

The Beemerville nephelite porphyry has been widely accepted as the type of sussexite. Iddings calculated the ratio

$$\frac{Na_2O+K_2O}{SiO_2}$$

for Brögger's grorudite-tinguaite series and found that the Beemerville rock, from Kemp's figures, lay upon a prolongation of the approximately straight line representing the series in the diagram.[2] The Beemerville rock, however, is not a differentiate at all, but, as we have shown, a textural variant of the main mass of the nephelite syenite.

[1] J. Morozewicz, *TMPM*, XXI (1902), p. 230.

[2] J. P. Iddings, *Jour. Geol.*, III (1895), p. 357.

SUMMARY

The scattered contributions to the geology and petrology of the alkalic igneous rocks of northern New Jersey are reviewed in chronological order, and a general account of these rocks is given.

The large mass of nephelite syenite northwest of Beemerville is described and is interpreted as a lenticular sill or a flat laccolith of foyaite, intruded by a mass of nephelite porphyry (probably a dyke) and by a small dyke of leucite tinguaite.

New analyses of the nephelite syenite (foyaite) and of the nephelite porphyry are presented, and the affinities of these rocks and of the leucite tinguaite are discussed. It is concluded that these three rocks are textural and mineral variants, without chemical differentiation, of the same magma.

It is shown that the nephelite porphyry is not a sussexite, as formerly supposed, and the status of sussexite as a rock variety is considered, with the conclusion that the name should be retained in its original sense, but that the nephelite porphyry of Beemerville can no longer be regarded as the type of the variety.

The presence of zirconium and the rare earths in the Beemerville rocks has been demonstrated, and the wide distribution of these elements in the region east of the Appalachians is briefly discussed.

WASHINGTON, D.C.
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INTRAFORMATIONAL CORRUGATED ROCKS

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INTRODUCTION

It is the purpose of this paper to enter into a general discussion of intraformational contorted rocks, with emphasis upon the modes of origin of the different types. During the last eighty years various examples have been described, but it is surprising how few are the cases which have been discussed in sufficient detail to furnish the data necessary for their classification on the basis of origin. Evidently these interesting and often puzzling structures have not received the attention which they deserve. In the present attempt to make a tentative genetic classification of intraformational corrugations, examples, mainly from American localities, are given to illustrate the various types. Because of the lack of certain critical data, it is difficult or impossible to be very sure of the proper classification of some of the cases.

DIFFERENTIAL MOVEMENT ACCOMPANYING THRUST FAULTING

Excellent examples of corrugated strata between practically undisturbed strata occur in the walls of the postglacial gorge at

Trenton Falls, New York, where the contorted beds lie at two distinct horizons within the Trenton limestone formation, there about 300 feet thick. The lower contorted zone, 4 to 6 feet thick, is visible only near the crest of the lower part of High Fall and in the upper end of the gorge near Prospect Village where the strata are highly inclined against a thrust fault surface. The upper contorted zone, 5 to 15 feet thick, is well exhibited along the path opposite High Fall (Fig. 1, upper part) from which place it is clearly traceable in the walls of the gorge for nearly 2 miles northward to Prospect (Fig. 1, lower part).

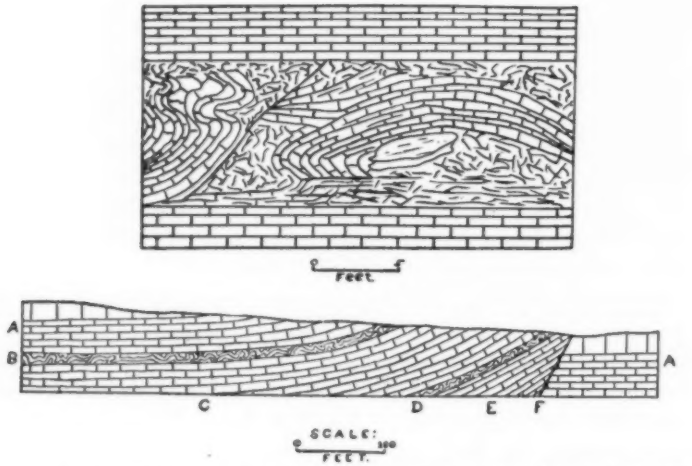

FIG. 1.—Upper figure: sketch of part of the upper contorted zone at Trenton Falls, New York. Lower figure: north-south structure section showing the positions of the contorted zones within the Trenton formation and their relation to the thrust fault at Trenton Falls, New York.

In both the undisturbed and the corrugated portions of the formation the impure limestone layers average only a few inches in thickness, and they are separated by thin partings of shale. Within the contorted zones the strata are in some cases scarcely disturbed; in some cases they are only gently folded or tilted; but most commonly by far they are highly folded, contorted, and even fractured.

The explanation offered by the writer is that the contorted zones were produced by differential movements within the mass of the Trenton limestone. The displacement (140 feet) of the thrust fault at Prospect Village was sufficient to cause the beds of the middle Trenton to be shoved over the upper Trenton. Figure 1 (lower part) shows the relation of the contorted zones to this fault. It is easy to see how, when the force of compression was brought to bear in this region, the higher Trenton beds on the upthrow side must have moved more easily and consequently faster than the lower Trenton beds. For instance, the portion *A* in Figure 1 (lower part) being separated from *C* by an intermediate mass *B* of possibly slightly less rigidity moved over *C* and caused the portion *B* to become ruffled or folded and fractured because this portion took up most of the differential movement. The portion *B* needed to be only slightly less rigid than the adjacent strata and this slightly reduced competency is due to somewhat thinner limestone layers separated by relatively thicker shale partings. A similar explanation applies to the lower contorted zone. According to this explanation the corrugated zones indicate horizons along which the differential movements took place, and no great amounts of differential movement were necessary to produce the contortions.

Grabau[1] states that

> These disturbances at Trenton Falls have been variously explained, the general conclusions of geologists being either: (1) that they were truly tectonic —lateral pressure having resulted in the folding of certain strata while others took up the thrust without deformation, or (2) that they were due to squeezing out of certain layers under the weight of overlying rock masses. Both explanations are unsupported by the detailed characteristics of the folds and their relationship to the enclosing layers.

The writer agrees that these two explanations must be ruled out, but he does not agree with Grabau who accepts Hahn's[2] subaqueous slumping or gliding hypothesis, described later in this paper, without even mentioning the tectonic differential slipping hypothesis (above outlined) which was first applied by the writer[3] to the Trenton

[1] A. W. Grabau, *Principles of Stratigraphy* (1913), p. 784.

[2] F. Hahn, *Neues Jahrb. Beil.*, Vol. XXXVI (1913), pp. 1–40.

[3] W. J. Miller, *Jour. Geol.*, Vol. XVI (1908), pp. 428–33.

Falls contorted zones in 1908, and further elaborated in 1915.[1] Arguments against Hahn's hypothesis are there entered into somewhat in detail. In the opinion of the writer, differential movement (not always as an accompaniment of thrust faulting) is involved in many, if not most, cases, of intraformational corrugations.

Intraformational contorted beds of essentially the same origin as those at Trenton Falls, only on a larger scale, occur within the straight-bedded limestones of Turtle Mountain, Frank, Alberta,

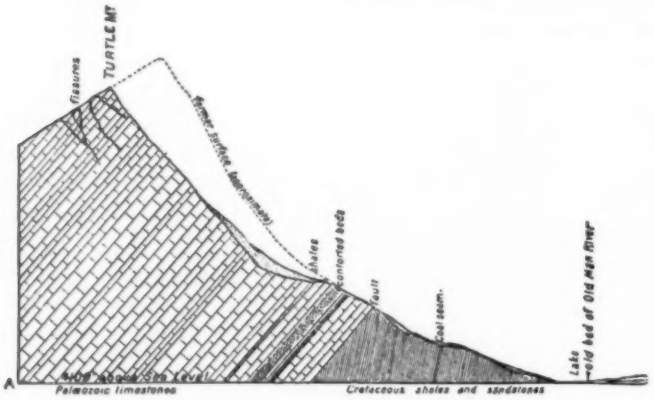

FIG. 2.—Section showing the position of the contorted limestones and the relation of the contorted beds to the great thrust fault at Frank, Alberta, Canada. (After R. W. Brock.)

Canada. Accompanying Figure 2 after Brock[2] shows the position of two corrugated zones of more shaly material intercalated between straight beds of limestone and parallel to a great thrust fault on its upthrow side. The writer would explain these corrugations as due to differential slippings within the limestone with resultant crumpling of the more shaly layers during the process of thrust faulting of the Paleozoic limestone over the Cretaceous strata.

Many years ago Logan,[3] in his description of a section 1,210 feet in thickness of Devonian strata on the Forillon peninsula of

[1] W. J. Miller, *N.Y. State Mus. Bull. 177* (1915), pp. 135–43.

[2] R. W. Brock, *Dept. Interior Canada, Ann. Rept.*, Part 8.

[3] W. Logan, *Geol. Can.* (1863), p. 391.

Gaspé in the Gulf of St. Lawrence, called attention to a remarkable example of intraformational corrugations. Logan says:

> It would appear as if the layers, after their deposit, had been contorted by lateral pressure, the underlying stratum remaining undisturbed, and had then been worn smooth before the deposition of the next bed. Where the inverted arches of the flexures occur, some of the lower layers are occasionally wanting as if the corrugated bed had been worn on the under as well as the upper side. The corrugations are precisely in the direction of the dip, and the peculiarity is not confined to a small part of the deposit.

He states that the same structure occurs at localities a mile apart.

FIG. 3.—Contorted strata within Devonian limestone at Cape Gaspé, Quebec. (After J. M. Clarke.)

John M. Clarke, who has observed the Gaspé occurrence, and who has kindly permitted the use of the accompanying picture (Fig. 3), says:

> Crinkled strata lying between strata which show no evidence of dislocation are not of infrequent observation but, in most of the recorded instances, the crinkled layer is of softer stuff (that is, a highly aluminous mud rock) than the rigid beds above and below. The brilliant exhibition of this phenomenon on the cliffs of Cape Gaspé, first sketched by Sir William Logan, is not of this character. Here the middle deformed beds are of thin limestone leaves like those which bound them. They are crumpled into sharp, much involved and overlapping curves in which the limestone plates are broken sharply across. It seems very doubtful if any other explanation can be brought forward for

this exceptional occurrence than that generally adopted for those of the first named category; a sliding of soft sea bottom deposits on a sloping surface under gravity, helped forward perhaps, if on a large scale, by earthquake shock or some other jolt-like impulse. . . . . It follows from the conception of these structures that the deformation was contemporaneous, and preceded the deposition of the overlying beds.[1]

For the reasons below listed the writer is strongly inclined to the conclusion that the corrugated zone at Gaspé developed as a result of differential movement within a great block of strata while it was being thrust faulted. (1) If we accept the hypothesis of subaqueous sliding, it is necessary to attribute the nearly straight upper surface truncating the contorted zone to erosion, but the very character and uniformity of both the contorted and inclosing strata seem to render this extremely improbable; (2) the worn character of both the upper and lower surfaces of the contorted zone, with certain beds locally missing as noted by Logan, are best explained on the basis of differential movement within the mass of limestone; (3) that the conditions were very favorable for differential movement is borne out by the fact that the contorted zone lies not far from the bottom of a large block of Devonian strata which has been extensively thrust faulted over Cambro-Ordovician strata; (4) the strike of the contorted zone is approximately parallel to the strike of the thrust fault; (5) the corrugations conform to the direction of dip of the inclosing beds; (6) according to Logan's section, the corrugations developed just where the conditions were most favorable for differential movement, that is, in the weakest (most shaly) part of a mass of the strata 200 feet thick with appreciably more arenaceous and resistant strata above and below this mass; and (7) the rather puzzling occurrence of the two nearly straight, thin beds within the contorted zone (see Fig. 3) may be more reasonably explained on the basis of differential movement than on the basis of subaqueous gliding because, as revealed by careful examination of the figure, these layers, as well as the layers capping the contorted zone, show clear evidence of having been deformed and even cut across locally by the corrugations, thus indicating that the contortions took place after deposition of those layers.

[1] Personal communication from Dr. Clarke.

DIFFERENTIAL MOVEMENT ACCOMPANYING NORMAL FAULTING

Up-drag of strata commonly takes place as a result of friction during movement on the downthrow sides of normal faults. Under proper conditions drag folds of the nature of intraformational corrugations develop as a result of differential movement of the bending strata. A good example has been observed by the writer in the bed of the Connecticut River just below the dam at Holyoke. A normal fault is clearly traceable in the bed rock across the river a few rods below the dam. From the fault south for 150 yards the strata (sandstone and shale) show dips of 25 to 40 degrees to the south due to up-drag, and they strike parallel to the fault. About 150 yards south of the fault there is a notably disturbed zone of thin-bedded dark shale with strike parallel to that of the fault. It shows clearly along the strike for 200 yards. The disturbed zone, varying in thickness between 4 and 10 feet, is overlain by fairly well-bedded red sandstone, and underlain by thin-bedded dark shale much like that of the disturbed zone. Next below there is sandstone. The folded zone does not terminate abruptly at either summit or base, but the top is much the more regular, coming close to the overlying sandstone. Even the sandstone, for a foot or so above the shale contact, is locally somewhat bent. The whole body of the rock in the bed of the river south of the fault plainly shows the effects of differential movements which took place during the process of normal faulting. One belt of weak, thin-bedded shale overlain by relatively rigid sandstone became moderately corrugated, the corrugations being of the nature of drag folds produced by differential movements. That the corrugations must have developed after the deposition of the overlying sandstone layers is proved by the fact that the lower part of the sandstone is in many cases moderately bent just like the immediately underlying shale. It seems impossible to escape the conclusion that this corrugated zone is of tectonic origin, that is, the result of differential movement accompanying normal faulting.

DIFFERENTIAL MOVEMENT ACCOMPANYING REGIONAL FOLDING

The principle of differential movement of strata is well illustrated in many regions of notably folded rocks. Differential move-

ments take place between the relatively more competent beds with not uncommon development of corrugations of the nature of drag folds between them. According to Leith: "The stronger beds tend to assume the 'parallel' type of folds in which the principal adjustment is between the beds rather than within them. This readjustment or slipping is concentrated in the intervening weaker layers. The folds of the weaker layers are really 'drag folds' due to differential movement between the controlling harder layers."[1]

Excellent examples of intraformational corrugated strata believed to have resulted from differential movement accompanying regional folding were observed by the writer some years ago at Baldhead Cliff near Ogunquit, Maine. The perfectly stratified thin-bedded rocks are there interbedded quartzite and phyllite. That the region has been subjected to severe lateral compression is evidenced by the fact that the strata stand in nearly vertical position. Figure 4 is a ground plan sketch showing the detailed structure of one of these corrugated zones about 9 feet thick, although the quartzite layers are really less conspicuous than indicated in the diagram. The corrugated zone, consisting very largely of phyllite, is not sharply delimited from the adjacent straight layers of predominant quartzite on either side. In most cases slight faulting has taken place along the axes of the sharp folds, but, as a rule, individual sharp folds or faults rarely extend all the way across the contorted zone. The folds are uniformly overturned toward the east. Fracture cleavage is well exhibited in the phyllite layers a few inches thick which lie within the quartzite on either side of the contorted zone. The cleavage cracks are uniformly inclined toward the east, as are the folds. "When a slate or shale is folded between two competent layers, such as quartzite, the cleavage produced in the slate affords clear evidence of slipping or shearing between the quartzite beds."[2]

All the evidence points to the tectonic genesis of the above-described intraformational corrugated strata. The corrugations must have developed after all the strata were deposited because the folded zone grades into the non-folded strata on either side.

[1] C. K. Leith, *Structural Geology* (1913), p. 114.

[2] *Ibid.*, p. 119.

Under conditions of differential movement the wide belt of predominant phyllite yielded by development of corrugations, while the thin bands of phyllite between much quartzite on either side yielded by development of fracture cleavage.

In the Marquette synclinorium of Michigan intraformational corrugations are shown on large scales in the slate formations which lie between quartzite formations.

During the summer of 1921 the writer was impressed by the fine exhibitions of intraformational contorted strata of Proterozoic

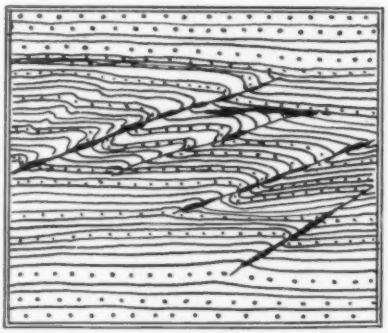

FIG. 4.—Ground-plan sketch of intraformational corrugated phyllite and quartzite near Ogunquit, Maine. The black lenses are quartz. Contorted zone about 9 feet wide.

age on both small and large scales in Glacier National Park. In the wall of the great Swiftcurrent cirque, only a few rods from the trail, the strata are notably folded and even crumpled through a thickness of 30 to 40 feet, and for a distance of a few hundred feet, while on all sides the strata are undisturbed except for the moderate regional tilting. The folding rocks are not sharply separated from the others. On the grand scale the strata are very irregularly contorted through a thickness of hundreds of feet in the face of the mountain between Gunsight Lake and Gunsight Pass with non-contorted strata above, and also at the same general horizon on either side. These contorted beds have quite certainly resulted from local differential movements within the great body of Proterozoic strata either during the development of the synclinal structure

of the park, or during the tremendous process of thrust faulting of the district, or both.

In a discussion of the highly folded gold-bearing series of Nova Scotia, Faribault[1] has figured and described some interesting cases of intraformational corrugated quartz veins in slate lying between beds of quartzite. He says: "Interstratified (quartz) veins often exhibit a remarkable folded or corrugated structure within the beds of slate that contain them. The corrugations, or crenulations, usually occur at or near the apex of the anticline, and run parallel with one another and in a direction approximately parallel with the axis of the fold." He believes (1) that the veins were formed during the folding of the region; (2) that, due to differential motion within the relatively weak or plastic slate containing veins which were formed early in the folding process, the veins and inclosing slate were corrugated; and (3) that such motion resulting in corrugations took place mainly at the apexes of the folds.

DIFFERENTIAL SQUEEZING ACCOMPANYING REGIONAL FOLDING

Lateral pressure may result in the folding of certain weaker strata while adjacent more resistant strata take up the thrust either without so much folding or by being fractured instead of folded. Intercalated beds of limestones are especially likely to yield in this manner. Interesting effects of differential squeezing in the folded Algonkian strata of the Marquette district of Michigan have been described by Van Hise, Bayley, and Smyth[2] who say:

> Along the contacts of the (Kona) dolomite beds and the quartz(ite) layers accommodation was necessary, and in places a bed of limestone may be seen bent into a series of anticlines and synclines, the overlying quartzite not being similarly bent, but being compressed and brecciated, thus making a pseudo-conglomerate. . . . . When the series was folded the more plastic limestone yielded to the pressure, in both a major and a minor way, by folding, while the brittle quartzite was fractured through and through, the movement of the fragments over one another, and of the beds as a whole, being sufficient to truncate the minor waves of the marble.

[1] E. R. Faribault, *Can. Geol. Surv., Guide Book No. 1*, Part 1 (1913), pp. 174–88.

[2] Van Hise, Bayley, and Smyth, *U.S. Geol. Surv., Mon. 28* (1897), pp. 242–43.

Even in this case some shearing action or differential slipping was a factor in the process.

Prouty[1] has described the crumpling of thin beds of marble between thick beds which latter yielded by fracturing and faulting.

The principle of differential squeezing appears to be not uncommon in various regions of folded strata.

DIFFERENTIAL MOVEMENT UNDER THE ACTION OF GRAVITY

Fine examples, believed by the writer to belong in this category of intraformational contorted strata, are to be found in the postglacial clays of various regions. The following observations made by the writer upon the clays in and near Northampton, Massachusetts, give a fair idea of the nature of the foldings and their origin. In the bank of the Connecticut River 2 miles east of Northampton, 12 to 14 feet of nearly horizontal, thin-bedded, perfectly stratified clays are overlain by 10 to 15 feet of stratified sands. The clay contains two contorted zones—a lower one 1 to 2 feet thick, and an upper one 4 to 8 inches thick—separated by 8 or 9 feet of the ordinary non-contorted clay. These corrugated zones are clearly traceable for several hundred feet. Immediately above each contorted zone, the non-contorted layers are in many places somewhat wavy or slightly folded. Different portions of the same contorted zone show different degrees of folding, the clay beds in some cases being only moderately folded, while in others they are intensely twisted, pulled apart, and even overturned. Some of the straight beds contain notable amounts of very fine sand, but the contorted beds consist of distinctly less sandy clay. The corrugations almost invariably have strikes parallel not only to each other but also to the notable dip (several degrees) of the clay beds in general. The under surface of each contorted zone is usually very straight, while the upper surface is commonly somewhat irregular (Fig. 5).

In the South Street clay pit of Northampton the writer has observed a very fine highly contorted zone of clay sharply intercalated between beds of clay whose stratification surfaces are almost straight. The straight beds consist of alternating, very fine-grained,

[1] W. F. Prouty, *Geol. Surv. Ala., Bull. 18* (1916), p. 170.

sandy clays and pure clays, while sandy clays are distinctly less conspicuous among the contorted beds. Figure 6 represents a detailed sketch of part of this corrugated zone, a feature of exceptional interest being the only slightly disturbed layer of fine-grained, sandy clay lying in the midst of the contortions. This contorted zone about 8 inches in thickness may be traced for a number of rods in the walls of the clay pit, but its full extent is unknown. Above it about a foot there is another corrugated zone lying between prac-

FIG. 5.—Highly contorted zone (8 inches thick) of clay between practically undisturbed beds of clay and sandy clay in the bank of the Connecticut River 2 miles east of Northampton, Massachusetts.

tically undisturbed beds. Within the clay pit the beds show a very appreciable dip of at least several degrees to the southeast.

It seems impossible to explain intraformational contorted clays like those just described except as a result of differential movements after the clays overlying the contortions were deposited. An explanation commonly given for such phenomena, but rarely if ever supported by anything like reasonable proof, is that the contortions were caused either by ice thrust, or the bumping or crowding of icebergs on surface layers which were afterward covered by more clays. Some facts opposed to such a hypothesis are: (1) the remarkably uniform thinness of the corrugated zones of such wide extent which could hardly have resulted from ice action upon surface layers, the development of such zones under considerable

weight of overlying materials being far more plausible; (2) there are no notable irregularities or depressions at the tops of the corrugated zones such as must have developed in the case of crumpling of surface layers with these depressions first filled by the succeeding deposits; (3) the moderate disturbance of the beds immediately overlying the corrugated zones, while those just underneath are distinctly straighter, strongly point to differential movements after the overlying beds were laid down; and (4) the only slightly disturbed thin bed of fine sandy clay in the midst of the contorted South Street clays, as well as the relatively straight beds of similar material just above and below the contortions, are best accounted

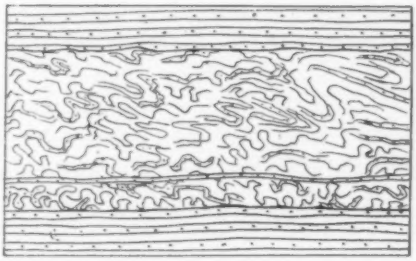

FIG. 6.—Contorted zone in South Street clay pit of Northampton, Massachusetts

for on the basis of differential movements, the thin, clay-rich, very plastic beds having yielded by crumpling, while the much less plastic sand-rich beds did not crumple. It is out of the question to look upon the upper surfaces of the corrugated zones as erosion surfaces because these perfectly stratified, thin-bedded, postglacial clays everywhere plainly show that they were deposited without a break in very quiet water.

The hypothesis of differential movement does not necessarily preclude the possibility of subaqueous slumping for it is plausible to think of differential movements within masses of the clays which may have shifted more or less down the gently sloping delta fronts in the postglacial lake of the Connecticut Valley. The action of gravity alone, or of gravity aided by an occasional earthquake, may have caused the movements. It is more likely, however, that

the movements mostly took place much later, that is, since the river has cut deeply into the distinctly dipping clay deposits so that, under the action of gravity or gravity aided by earthquake shocks, overlying beds have moved differentially over lower-level beds in the general direction of the dip. In some local cases differential movements within clays may possibly have been caused by the crowding action of ice against upper portions of clay deposits as explained later under another caption.

A few examples of apparently similar intraformational clays from other regions will be cited, with various explanations which have been offered to account for them. In regard to corrugations in clays near Boonville, New York, Vanuxem[1] eighty years ago said: "These interesting forms of disturbance were no doubt the result of unequal, local, and lateral pressure." A very similar excellent example of intraformational sand and clay in the Devil's Lake region of Wisconsin is figured and described by Salisbury and Atwood,[2] who say: "The grounding of an iceberg on the surface before the overlying layers were deposited, or the action of lake ice, may have been responsible for the singular phenomenon."

M. E. Wilson has described and figured[3] interesting cases of intraformational contorted and broken clays in Timiskaming County, Quebec, and in regard to their origin he says: "Whatever the cause of these peculiar deformational structures, it is evident that they were contemporaneous with deposition, for the stratification is uniform in both the overlying and underlying beds."

In Albany County, New York, according to Nason,

> A layer of blue clay about a foot in thickness and one hundred feet long is crumpled and gnarled, appearing as though its laminae had been disturbed by some dragging or shoving weight, while above and below the layers are exactly parallel and wholly undisturbed. . . . . Bearing in mind the fact that the clay banks are underlain by sand, the water circulating through these sands gradually undermines the clay bank and tilts it to such an angle that one part of a bed would slide over the other, only leaving visible marks along the particular stratum disturbed, and in the form of crumplings. Many of the clays lie at an angle to the horizon, and only a slight tilt would suffice to give rise to a slip.[4]

[1] L. Vanuxem, *Geol. N.Y.*, Part 3 (1842), p. 215.

[2] Salisbury and Atwood, *Jour. Geol.*, Vol. V (1897), p. 143.

[3] M. E. Wilson, *Can. Geol. Surv., Mem. 103* (1918), p. 142 and Pls. 15–16.

[4] F. L. Nason, *N.Y. State Mus. Rept. 47* (1893), p. 465.

It is to be noted that Nason's explanation clearly involves the principle of differential movement which is advocated by the present writer as the cause of most intraformational contorted clay beds.

SUBAQUEOUS GLIDING OR SLUMPING

The hypothesis of subaqueous gliding has been elaborated by Hahn[1] who has considered most cases of intraformational contorted strata to belong in that category. According to Hahn's hypothesis a lenslike mass breaking loose from any cause (e.g., earthquake shock) would glide down a subaqueous slope and, because of the striking of some obstacle on the bottom and increased friction and water pressure, the gliding mass would come to rest only after it had become considerably deformed or contorted. Sediments would then be deposited in normal order on top of the crumpled layer. The most intense folding would be toward the front of the transposed mass, and of course the strike of the folds would be at right angles to the direction of the moving mass. Conditions for such gliding are regarded as favorable at many places on the marginal sea bottom.

In the paper above cited, Hahn especially refers to the intraformational contorted zones at Trenton Falls, New York, as typical examples of submarine slumping among ancient strata. In a paper already published the writer has given reasons for believing that Hahn's hypothesis cannot possibly account for the Trenton Falls occurrences.[2] Hahn has regarded most cases of intercalated corrugated strata as results of subaqueous gliding, while the present writer regards most of them by far as results of differential movements within the masses of strata.

T. C. Brown[3] has described what appears to be a clear case of intraformational folding in Paleozoic strata near Bellefonte, Pennsylvania. In regard to this occurrence Brown says in part: "At periodic intervals these beds of calcareous mud and intermingled pebbles slumped or slid along the bottom under the influence of gravity. At the time of the slump or slide the matrix around the pebbles consisted of incoherent lime mud or paste. As it moved

[1] F. Hahn, *Neues Jahrb. Beil.*, Vol. XXXVI (1915), pp. 1–41.

[2] W. J. Miller, *N.Y. State Mus. Bull. 177* (1915), pp. 140–43.

[3] T. C. Brown, *Jour. Geol.*, Vol. XXI (1913), pp. 241–43.

it developed unsymmetrical waves or ripples in its mass." After the mass came to rest more lime mud was deposited upon its surface. Since then the whole has been solidified. The contorted zone shows notable variations in thickness from a few inches to several feet (Fig. 7). Certain criteria which seem to rather definitely place this occurrence in the category of subaqueous gliding, and which particularly distinguish it from the above-described examples believed to have resulted from differential movements after deposition of the overlying layers, are the following: (1) the notable variations in thickness of the contorted zone locally, even within a few feet; (2) the very irregular upper surface of the folded zone,

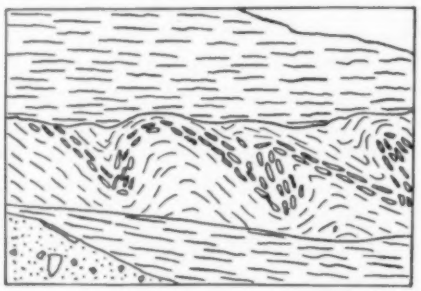

FIG. 7.—Folded limestone and limestone-conglomerate, several feet thick, between non-folded beds near Bellefonte, Pennsylvania. (After T. C. Brown.)

and the rather regular under surface; (3) the bulging of the immediately overlying strata over the little anticlinal folds; and (4) the distinct evidence of the filling of the depressions on the upper surface of the corrugated zone before the general layers of overlying materials were laid down.

D. W. Johnson has kindly allowed me to reproduce a picture (Fig. 8) of a moderately corrugated zone within the cross-bedded Triassic red beds near Kanab, Utah. Regarding the occurrence he says:

> The crumpling and faulting must have taken place during the process of deposition, for the erosion plane beveling the deposit a few inches above the corrugations, and upon which the next layer of cross-bedded sand was deposited, shows no disturbance. I have therefore attributed the corrugations and miniature faults to slumping or settling of the deposit as it was built forward, delta-like, under the influence of current action.[1]

[1] Personal communication from Professor Johnson.

In view of the fact of the very moderate degree of corrugation, a slight amount of subaqueous slumping or forward settling, perhaps under earthquake impetus, would have produced the structures. There may have been no actual gliding over the lower erosion surface at all. Erosion intervals, under the conditions of shifting currents during the deposition of the cross-bedded sandstones, would be expected. The corrugations of the disturbed zone might possibly have resulted from slight differential slipping

FIG. 8.—Intraformational cross-bedded, corrugated, Triassic sandstone near Kanab, Utah. (After D. W. Johnson.)

along the erosion surfaces but, in spite of certain outward resemblances to the intercalated contorted zones above described as due to differential movement after deposition of the immediatley overlying beds, the writer believes that the structures in the Kanab occurrence are essentially different, and that they are correctly interpreted by Johnson.

Norton[1] has discussed subaqueous gliding as a cause of a certain type of breccias, but examples certainly coming under this category are apparently not common.

[1] W. H. Norton, *Jour. Geol.*, Vol. XXV (1917), pp. 182–85.

ACTION OF ICE

Intraformational contorted clays have, by various writers, been attributed to the action of ice but, as a rule, there has been little or no attempt to really analyze the structures involved. Salisbury and Atwood,[1] in their discussion of an extinct glacial lake near Devil's Lake, Wisconsin, figure and very briefly describe intraformational contorted clays. They say: "The grounding of an iceberg on the surface before the overlying layers were deposited, or the action of lake ice, may have been responsible for the singular phenomenon." In accordance with criteria set forth in the foregoing discussion of the Connecticut Valley clays, the writer believes that this corrugated zone must have resulted from differential movement after deposition of the overlying beds. The remarkable uniformity of thickness of the contorted zone; its relatively regular (nearly straight) upper surface; and the gently bent immediately overlying beds all strongly indicate that the corrugations developed under weight of the overlying beds. If the corrugations were caused by thrusting action of ice upon surface layers would not the contorted zone show notable variations in thickness and irregularity of its upper surface, and would not the overlying beds fail to show appreciable evidence of having been deformed? It is, however, conceivable that the corrugated zone may have resulted from differential movement brought about by the crowding action of ice against the upper portion of the whole body of clay, thus setting up a differential motion within its mass. Either this, or differential movement brought about under the action of gravity (in case the clays are at least moderately tilted), appears to have produced the corrugations.

J. Geikie,[2] in his description of the early postglacial deposits of the basin of the Forth in Scotland, says:

> Here and there also the beds (sands and clays) are much crumpled and confused, great sheets of clay being rolled over and over, and involving the associated sands for considerable distances. . . . . These are exceedingly irregular, and are just of such a character as we should expect would result from the grounding of ice rafts.

[1] Salisbury and Atwood, *Jour. Geol.*, Vol. V (1897), p. 143.

[2] J. Geikie, *The Great Ice Age* (1894), pp. 271–72.

Such contorted zones were quite certainly produced before the overlying clays were deposited, as proved by the notable variation in thickness of the contorted zone, its very irregular upper surface, and the manner in which the perfectly undisturbed overlying clays were laid down on the irregular surface.

W. A. Johnston[1] has described and figured an interesting case of notably crumpled sand forming a zone of variable thickness under till near Fort Frances, Ontario. He says that the crumpling of the sand was due to the over-riding action of glacial ice.

DIFFERENTIAL WEIGHTING

Kindle,[2] in his discussion of deformation of unconsolidated beds on the Avon River, Nova Scotia, describes "a section of finely laminated horizontal silts, which, for a thickness of one foot or more near the middle, have been distorted into a highly convoluted zone." He advances the hypothesis of differential weighting to account for the phenomenon and says:

> If a heavy load of sand were deposited over a portion of an area in which very soft beds were interpolated between more coherent strata, the more mobile would be likely to squeeze outward away from the sand pressure toward an unsupported edge, if one were developed by stream or wave cutting. This might occur without disturbing firmer beds above and below through the more yielding character of the soft beds.

According to Kindle, current scour would remove the heavier and coarser beds, after which horizontal layers would be deposited over the disturbed beds. He describes experiments in which clay beds in glass tanks were notably deformed by differential weighting with shot.

Some reasons for thinking that the foregoing explanation is not applicable to the Avon River occurrence, and quite certainly not to intraformational contorted clays in general as typified by the Connecticut Valley occurrences above described, are as follows: (1) Quite generally, in nature, there is no evidence of anything like notable current scour, but rather there has been continual deposition of the clays; (2) in the experiments the surfaces of the deformed

[1] W. A. Johnston, *Can. Geol. Surv., Mem. 82* (1915), p. 43 and Pl. 8.

[2] E. M. Kindle, *Geol. Soc. Amer. Bull.*, Vol. XXVIII (1917), pp. 323–32.

zones are very irregular, while in nature they are usually very regular, or even straight, for long distances; (3) such regular surfaces could hardly have resulted from vigorous current scour because the contorted zones are usually remarkably uniform in thickness for long distances; (4) there is almost invariably no evidence for the present or former existence of materials of such arrangement and character directly over the contorted zones as to give rise to very appreciable differential weighting; and (5) the contorted beds are seldom very much softer or more mobile than the inclosing strata.

CRYSTALLIZATION AND HYDRATION

In certain types of rocks, like gypsum and salt, there is strong evidence for the development of intraformational deformative effects by crystallization (or hydration) after their deposition. In the Zechstein salt of Germany,

> where the enclosing rocks are undisturbed, the layers of brightly colored bittern salts and of gypsum often show a remarkable flexuous, sinuous, or disrupted character. . . . . In the Salina deposit of central New York, some of the alternating salt and gypsum layers occasionally show a pronounced flexing and overfolding, while others are wholly undisturbed.[1]

In his discussion of the salt beds of western central New York, Luther[2] has reproduced an interesting picture of a small sharply overturned fold of rock salt between practically undisturbed beds.

The above-described examples occur in regions of non-folded and non-faulted strata, and it seems quite certain that "the main force was the endogenetic one due to the crystallizing force of the salts and to metasomatic process" (Grabau after Arrhenius).

Very fine examples of corrugations and crenulations occur within the gypsum deposits at Hillsborough, New Brunswick. According to Ami[3] "the gypsiferous deposits present evenly banded structure, between which there occur neatly folded layers in the form of ribbon-like corrugations" (Fig. 22). Kramm[4] states that "the gypsum rests upon a bottom of anhydrite and reaches a maximum thickness of perhaps 125 feet," and that gypsum was derived by

[1] A. W. Grabau, *Principles of Stratigraphy* (1913), p. 757.
[2] D. D. Luther, *N.Y. State Mus. Rept. 50*, Part 2 (1896), Pl. 4.
[3] H. M. Ami, *Geol. Soc. Amer. Bull.*, Vol. XXV (1914), p. 37.
[4] H. E. Kramm, *Can. Geol. Surv., Guide Book No. 1*, Part 2 (1913), p. 364.

hydration of anhydrite, as can be observed in many places. Since the gypsum beds occur in a very shallow syncline, the highly crenulated intercalated layers cannot have been caused by regional folding. The cause was, no doubt, the force exerted within the whole mass as a result of the great expansion during the transformation of anhydrite to gypsum. Differential stresses and strains set up locally in the whole mass caused localization of the corrugations (Fig. 9).

FIG. 9.—A specimen of gypsum from Hillsborough, New Brunswick, showing highly folded layers between less folded layers.

PRESSURE OF INTRUDING MAGMAS

Among the pre-Cambrian rocks of the Adirondack Mountains, New York, the writer has observed excellent examples of intraformational corrugations which are believed to have been direct effects of the pressure of magmatic intrusions. He has presented evidence[1] to support the view that the very ancient Grenville stratified series has never been subjected to severe regional folding throughout most or all of the Adirondacks. During the intrusion of the tremendous volumes of syenite-granite magma, the Grenville series was, however, badly cut to pieces so that many masses, both small and great, were tilted about in the rising magma and in many places subjected to notable differential pressure. The limestones, especially where they are near contacts with the syenite-

[1] W. J. Miller, *Jour. Geol.*, Vol. XXIV (1916), pp. 595–96.

granite, much more commonly exhibit local corrugations or crumplings than the other more rigid strata. Where a mass of the Grenville strata contains zones of well-bedded limestone intercalated between more rigid strata, and the whole has been subjected to differential pressure by the invading magma, the limestone layers have not uncommonly become contorted by differential movement within the mass while the adjacent beds above and below have been deformed little or not at all. In Figure 10, which well illustrates such a phenomenon in northern New York, the contorted beds of

FIG. 10.—Crumpled beds of impure, thin-bedded, crystalline limestone between beds of only slightly disturbed garnetiferous gneiss north of Hermon, St. Lawrence County, New York.

very plastic impure limestone lie between heavy beds of rigid garnetiferous gneiss. This contorted limestone and its associated gneiss form part of a long narrow body of Grenville strata which was included in, and subjected to differential pressure by, a large body of granite magma, causing the more plastic limestone beds to crumple.

Spurr,[1] in his discussion of the Silver Peak region of Nevada, publishes a fine picture of intraformational contorted strata which occur on Mineral Ridge. In this region large volumes of granite magma invaded and cut to pieces Paleozoic strata made up of

[1] J. E. Spurr, *U.S. Geol. Surv. Prof. Paper 55* (1906), p. 108 and Pl. 21.

a comparatively thick series of thin-bedded, shaly, and calcareous sediments intercalated with beds of pure limestone, now metamorphosed into marble. The thin-bedded sediments are sometimes carbonaceous, sometimes streaked with sandy material. . . . . The limestone-slates are contorted on a minor scale. Most of this crumpling was probably due to the intrusion.

Beyond the last sentence quoted, Spurr says nothing regarding the cause of the intraformational crumpling. The available data rather clearly indicate that these corrugations, like those above described as occurring in northern New York, have been caused by the magmatic intrusion where a block of strata was more or less completely surrounded by the magma and subjected to differential movement, causing the more yielding layers to crumple.

Between 5 and 6 miles north of Northampton, Massachusetts, the writer has observed excellent examples of local contortions within the Leyden argillite (Paleozoic) formation near its contact with a basic phase of the Williamsburg granite. For about 2 miles parallel to the contact, irregularly distributed contortions are highly developed in the argillite for 10 to 20 rods out from the contact. Beyond that they rapidly diminish to disappearance. From the field evidence it seems clear that the corrugations resulted from differential movements within the argillite, caused by the shouldering pressure of the rising magma.

ACTION OF MAGMATIC INJECTION

In certain regions magmatic injection schists and gneisses contain local portions which are highly contorted. Many observations of such phenomena have been made by the writer in his study of the Adirondack Precambrian rocks. The following brief description of a certain district may best serve to illustrate the main principles involved. Extending 2 miles northeastward from just north of the village of Russell, St. Lawrence County, New York, there is a wide belt of mixed rocks containing fine exposures of amphibolite and garnetiferous gneisses intimately cut and injected, mostly parallel to the foliation, by moderately coarse-grained granite and pegmatitic granite, the whole mass being conspicuously banded. Just north of the village most of the mixed rock is notably contorted, while one-fourth to one-half of a mile farther east most of the rock is relatively straight-banded, but contains local highly contorted

zones. Still farther east the mixed rocks are nearly all straight-banded. It is believed that, during the forcing in of the magma, the whole mass of rock was notably plastic, and that local differential movements within the mass, caused by unequal pressures of the rising magma, resulted in the local corrugations.

MAGMATIC FLOWAGE

Finally, in our discussion of intraformational contorted rocks, differential magmatic flowage should be mentioned as a cause. Within certain areas of plutonic igneous rocks which exhibit primary foliation, there are not uncommonly local zones or bands in which the gneissoid structure, accentuated by dark minerals, appears to be irregular, wavy, or even contorted. The writer's experience in the Adirondacks shows[1] such local, contorted, primary flow-structures to be very common there, especially in the great syenite-granite series, and it is believed that they are essentially the result of varying magmatic currents under differential pressure, principally during a late stage of magma consolidation.

Lawson[2] has noted similar structures within certain granites of the Rainy Lake region of Ontario. He says: "The lines of streaking are very often not straight, but are wavy or contorted, sometimes intricately so, and are evidently due to slow movements in the magma prior to final consolidation."

[1] W. J. Miller, *Jour. Geol.*, Vol. XXIV (1916), pp. 611–12.

[2] A. C. Lawson, *Can. Geol. Surv., Mem.* 40 (1913), p. 93.

THE PHYSICAL CHEMISTRY OF THE CRYSTALLIZATION AND MAGMATIC DIFFERENTIATION OF IGNEOUS ROCKS

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Trondhjem, Norway

(Continued from page 649 of Vol. XXIX)

V

THE INFLUENCE OF PRESSURE

A

The dependence of the melting point on uniform[1] pressure is designated, as is well known, by the formula established by Clausius-Chapeyron:

$$\frac{\Delta T}{\Delta P} = 10.333 \cdot \frac{T(v_{liquid} - v_{solid})}{E.\ q.},$$

$\frac{\Delta T}{\Delta P}$ designating the alteration of the melting point in C° per increase of atmospheric pressure, T the melting point in absolute temperature (starting from $-273°$), q the latent melting heat in gr. cal. pr. gr., v the specific volume (in cm^3 per gr.) at the melting point—$v_{liq.} - v_{sol.}$ accordingly meaning the difference of specific volume between the liquid and the solid phase at the melting point—and $E = 425$.

In by far the most substances $v_{liq.} - v_{sol.}$ is positive at common and at moderate pressures. Accordingly the minerals, when melting, must, as a general rule, expand in volume or become of lower specific gravity. The case is entirely the reverse of that of ice and of bismuth.

[1] Within a liquid, such as a magma, also in the case that more or less mineral has already crystallized, the pressure always becomes uniform or hydrostatic, and in this case the formula quoted is applicable. Quite different is the case of *non-uniform* compression (and stress) in the solid phase. I beg to refer to a series of publications of recent years (see the review of John Johnston in this Journal, XXIII [1915], p. 732).

G. Tammann, as is well known, has pointed out that for many salts, $v_{liq.} - v_{sol.}$ decreases with increasing pressure so that, when the pressure is extraordinarily high, for instance 5000–10,000 atmospheres, it approaches zero; at still higher pressure the difference may be negative. However, this is not the case of substances in general. Thus P. W. Bridgman[1] has experimentally ascertained that, in a great many substances (metals and some salts, etc.), on pressures rising to 12,000 atmospheres (corresponding, for a magma, to a depth of about 40 kilometers), $v_{liq.} - v_{sol.}$ remains positive—indeed with gradually (somewhat) decreasing magnitude for increasing pressure. Some substances, even at the enormous pressures just mentioned, show but an inconsiderable decrease of the difference of volume, and J. Johnston and L. H. Adams[2] showed, for a number of metals, under a pressure of up to 2000 atmospheres (corresponding, for a magma, to a depth of about 7.5 kilometers), a rectilinear course of the difference of volume.

Under a pressure of one atmosphere all the silicate minerals hitherto examined show, at room-temperature, a lower specific gravity for the glass, that is the extreme viscous fluid phase, than for the crystalline, that is the solid phase.

According to what we have stated above, we must take it for granted that for rock-forming minerals $v_{liq.} - v_{sol.}$ is in all cases positive, and that the difference of volume existing for a pressure of one atmosphere will remain nearly constant, at any rate down to depths of a few kilometers, and that even to depths of 5 or 10 kilometers it will show practically no or only a little decrease.

As far as the common rock-forming silicate minerals are concerned, the *latent melting heat* is very high throughout. In fact for minerals melting at about 1200° to 1400° or 1500°, it amounts to about 90 or 100 gr. cal. pr. gr.—for some a little more and for some a little less.[3]

[1] *Proc. Amer. Acad.*, XLVII (1911–12) and *Physic. Rev.*, III (1914).

[2] *Zeits. f. anorg. Chemie*, 72 (1911), and *Amer. Jour. of Sci.*, XXXI (1911).

[3] As for anorthite (melting point 1550°), diopside (1391°), åkermanite (about 1310°) and fayalite (about 1075°),I have in earlier publications (Silikatschmelzlös. II [1904], with correcting calculation in my publication on slags in Doelters, *Handb. d. Mineralchemie*, I [1912], p. 942) determined the latent melting heat at respectively about 105, 94, 90, 80 cal., with an error limit of ±15 or 20 cal. For anorthite Bowen

Thus the divisor of the formula becomes very great, and consequently the melting point of the silicate minerals rises but very little on increasing pressure.[1] As an illustration I cite a case treated in my publication just quoted:

For a mineral with melting point = 1200°, melting heat = 100 cal., density in the solid phase = 3.000 and in the fluid phase = 2.887, $v_{liq.} - v_{sol.}$, at the melting point accordingly amounting to 0.013 or 3.9 per cent we calculate the melting point at higher pressures:

Pressure	Depth below the Surface	Melting Point
1 atmosphere	0 kilom.	1200°
270 atmospheres	1 kilom.	1201.3°
2700 atmospheres	10 kilom.	1213.5°
10,000 atmospheres	37 kilom.	1250°

We have assumed, in this instance, in accordance with an early examination carried out by C. Barus,[2] a percentage value of 3.9 per cent, for the difference (at the pressure of one atmosphere) between the specific volume in the fluid and in the solid phase of the melting point, and we assume also the same value at higher pressure.

A series of determinations of glass and of crystalline substance at room-temperature (15° or 20°) show, for rock-forming minerals and for rocks, the following percentage differences of specific volume:[3]

In some cases only about 3 per cent (2.9–3.5 per cent), in most cases between 5 and 8 per cent, exceptionally up to 10.6, 11.4, and in a single case 13.6 per cent.[4]

(in his study on plagioclase, *loc. cit.*) has calculated 104.2 cal. (I found 105 cal. ± 20 per cent.) For diopside W. P. White (*Amer. Jour. Sci.*, XXVIII [1909], p. 486, footnote), according to a preliminary determination, states 106 ± 15 cal. (I found 94 ± 15 per cent.)

[1] I beg to refer to my statement in *Tscherm. Mitt.*, XXVII (1908).

[2] *Phil. Mag. London*, XXXV (1893), and *U.S. Geol. Surv. Bull. 103.*

[3] Most of these statements are grouped from Doelters, *Handb. d. Mineralchemie*, I (1912), p. 672.

[4] The last named value concerns $CaMgSiO_2O_6$ with density of the mineral diopside = 3.275, and of the glass = 2.830 (Allen, White, etc., *Amer. Jour. of Sci.*, XXVII [1909], $v_{liq.} - v_{sol.}$ accordingly = 0.3533 − 0.3053 = 0.050.

These figures, however, cannot be transferred so as to be applied at the melting point without being corrected, as the crystalline and the glassy phase will, as a general rule, differ a little as to volume dilation.

The only precision investigation known to me of the specific volume of a silicate at the melting point, has been carried out by A. L. Day, R. B. Sosman and J. C. Hostetter,[1] who determined for a diabase:

At 20° in the crystalline phase dens. = 2.975 (specific volume = 0.3362) and in the glassy phase dens. = 2.763 (specific volume = 0.3620), the percentage difference at 20° accordingly, amounting to 7.1 per cent, the glass being taken as the starting point.

This percentage difference increased at the melting point to 9.1 as a minimum and 10.9 as a maximum, and next to the last figure, accordingly to about 10.5 per cent corresponding to a difference = *ca.* 0.041 of the specific volume.

From what we have stated above, we take it for granted that, at the melting point of the common rock-forming minerals (melting at about 1200–1500°), $v_{liq.} - v_{sol.}$ will, as a general rule, vary between the limits of about 0.015 and 0.045. Assuming a melting heat of 100 cal. and a melting point of respectively 1200° and 1500°, we shall have, for a pressure of 1000 atmospheres, corresponding to a depth of about 3.7 kilometers, a rise of temperature of respectively about 5–6° and about 15–18°. That is to say, in igneous flows, at depths of up to 0.5 or 1 kilometer, the melting point of the different minerals only rises between about 1° and about 4 or 5°, while in deep-seated rocks, in which the crystallization takes place at depths of 5, 10, or 15 kilometers, there may be involved a rise varying respectively between about 6° and 30°, between about 12° and 40°, and between about 15 or 20° and 60°.

Thus, even in deep-seated rocks crystallizing at very great depths, the rise of the melting point is rather inconsiderable. And it should be particularly emphasized that the *difference* of rise of the melting points of the various minerals crystallizing in one and the same magma, will only amount to some few degrees; even in deep-seated rocks the difference is rather small, in fact rarely amounting to more than 10, 20, or perhaps in some cases 40°.

[1] *Amer. Jour. of Sci.*, XXXVII (1914).

As to the *dislocation of the eutectic* by uniform pressure, H. W. Bakhuis Rooreboom[1] has stated that in this case also the formula of Clausius-Chapeyron is applicable. The rise of temperature of the binary (and the ternary) eutectic of the rock-forming minerals by pressure may consequently be measured by the same *small* measures that have just been indicated for the minerals themselves.

Moreover, it is to be noted that the tangent to the melting curve near the origo (respectively 100 per cent *a* and 100 per cent *b*) is determined by the factors: T (absolute temperature), q (melting heat), and the electrolytic dissociation which three factors are but little dislocated by pressure, and finally the molecular weight which is constant if no polymerisation takes place. In other words, the melting curve in a binary system (Fig. 50) near the origo will, at high pressure, take a course parallel to that of the melting curve at low pressure. The further course of the melting curve is also essentially determined by the constants just mentioned, which are generally very little dislocated by pressure. This relates to the general experience that pressure has but little influence on the solubility of the mutual solutions, provided that no vapor phase is present.

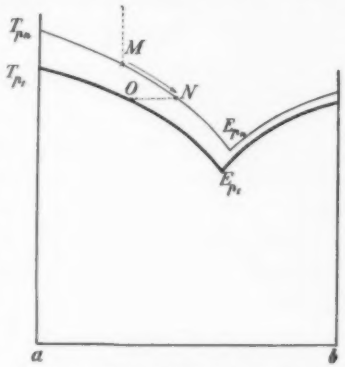

FIG. 50.—Illustrating the unessential dislocation of the composition of the binary eutectic by uniform pressure.

T_{p_s}, T_{pn} = melting point and E_{p_s}, E_{pn} = binary eutectic by respectively low and high pressure.

The contents of *a* and *b* at the intersecting point of the curves, in other words the composition of the binary eutectic, (E_{p_s} at low pressure, and E_{pn} at high pressure) will accordingly be but very little dislocated by pressure. And this accords with the fact that the temperature of E_{pn}, as just stated, is only very little higher than that of E_{p_s}. This reasoning can also be extended so as to be applied to the ternary and still more complex eutectics.

[1] *Heterogene Gleichgewichte*, II (1904), p. 715.

The error made by transferring the determination of the *composition of the eutectic on a pressure of one atmosphere*, to be applied also to the *pressure prevailing during the crystallization of the eruptive rocks*, will accordingly be *rather unimportant provided that the minerals involved are formed independently of pressure.*

I have demonstrated this fact by some petrographic instances in my publication in *Tscherm. Min. Petrogr. Mitt.*, XXV (1906), and XXVII (1908). I will here only point out that the analyses of the final eutectic quartz: feldspar-product from igneous flows, formed at a comparatively low pressure, accord within the limits of error exactly with the corresponding final product from granitic deep-seated rocks and also with the graphic granite in the Archean granite-pegmatite dikes formed at very great depths (see the analysis No. 1–40). And I deem it right to employ the experimentally determined eutectic Qu:An, at a pressure of one atmosphere, for parallellism with the eutectic Qu:Ab in deep-seated rocks or granite-pegmatite dikes (Fig. 3).

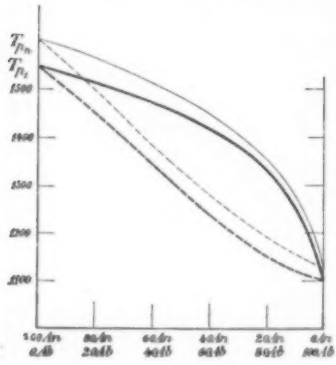

FIG. 51.—Illustrating the unessential dislocation of the *horizontal* difference between the liquidus and the solidus curve of the An : Ab-system by low and high pressure.

T_{p_1}, T_{p_2} = melting point by respectively low and high pressure.

The same general reasoning as to the inconsiderable influence of pressure on the dislocation of the melting point and on the eutectic may be transferred, in all essentials also to *mix-crystal systems*, or at any rate, to the continuous mix-crystal systems of type I.

For example, let us consider Ab:An. Even if the melting point of An should, at high-pressure, rise a little more or a little less than of Ab, it must be presumed a priori that the course of the liquidus and the solidus curves, and, what is petrographically of the greatest importance, the *horizontal distance between the liquidus and the solidus curves*, will remain almost the same (Fig. 51) at a high pressure

(p_n) as at a low one (p_i). This is also verified by petrographic experience. Thus in effusives and dike-rocks with a proportion Ab:An, fixed from the analysis of the whole rock, the mix-crystal first separated had nearly exactly the same composition as in a melt of Ab+An crystallizing at a pressure of one atmosphere.[1]

B

The formula of Clausius-Chapeyron quoted (p. 611) is to be applied also to the dislocation, at uniform (hydrostatic) pressure, of the *inversion point* between two reversible solid phases of one and the same substance.

The volume difference $v_1 - v_2$, in this case, involves the difference between the solid phases stable at higher and lower temperature, and the melting heat must be replaced by the inversion heat.

Also here $v_1 - v_2$ is in most cases positive, and only exceptionally negative.[2]

The *inversion heat* between two solid phases of one and the same substance is, so far as we now know, always positive and generally very small, sometimes low even almost to zero, and in most cases it amounts only to a small fraction of the melting heat.[3]

For metals, sulphides, silicates, etc., the divisor of the temperature: pressure formula thus becomes, as a general rule, very small,

[1] I refer, on this subject, to a comparison between my account in *Tscherm. Mitt.*, (1905), of the mix-crystal system Ab:An in igneous rocks and the diagram of Bowen (cf. Fig. 2, dating from 1912–13) for the Ab:An melt at the pressure of one atmosphere. The analyses of the plagioclase first separated in the rocks concern partly plagioclase somewhat zonally constructed, and partly plagioclase that has grown a little poorer in An and richer in Ab on account of partial equilibrium of the solid and the liquid phase. The plagioclase mix-crystal first separated in andesites, dacites, etc., will, accordingly, have been somewhat richer in An and poorer in Ab than is indicated in the analysis tables on pages 503 and 512 in my publication in *Tscherm. Mitt.*, XXV (1905).

[2] As an instance of negative $v_1 - v_2$ is mentioned: The density of the three modifications of Ca_2SiO_4 amounts to: of α (at a high temperature) = 3.27, of β = 3.28, and of γ (at a low temperature) = 2.97. The density of common stannum is = 7.3, that of the gray tin formed at a low temperature (undercooled much below +20°) is only = 5.8. Both in the passage from β to γ-Ca_2SiO_4, and from the common white stannum to the gray one, so great an increase of volume takes place that the substance is disintegrated by itself.

[3] However, to this rule also there are some exceptions. The most striking instance is formed by lithiumsulphate having an inversion heat even five times greater than the melting heat (Hüttner und Tammann, *Zeit. f. anorg.*, Ch. 43 [1903]).

and consequently the inversion temperature, even if $v_1 - v_2$ only amounts to a medium positive value, will have a not quite inconsiderable rise on increasing pressure. And if $v_1 - v_2$ is considerable (and positive) the *rise of inversion temperature owing to pressure will be exceedingly great.*[1]

This has been experimentally examined for monoclinic and orthorhombic sulphur (monocline S, on pressure of one atmosphere having its melting point at 119.25°, density = 1.98, melting heat, = 12.5 cal. 1 inversion temperature between monoclinic and orthorhombic S, on pressure of one atmosphere = 95.6°, inversion heat = 2.52 cal., density of orthorhombic S = 2.07 and melting point = 112.8).

On pressure the inversion temperature between monoclinic and orthorhombic sulphur rises more than the melting curve of monoclinic sulphur. The two curves intersect at a pressure of 1320 kilogrammes pr. cm² (= 1275 atmospheres) and at a temperature of 151°, and at *still higher pressure only orthorhombic sulphur may be formed.*[2]

Accordingly it will not be surprising that, in the case of a rock-forming mineral which at low pressure has an α-form (at high temperature) as well as a β-form (at lower temperature), it should always be the β-form,[3] or the form stable at lower temperature, that crystallizes in eruptive rocks formed at high pressure.

Let us consider particularly some of the most important modifications of SiO_2:

The inversion from α-cristobalite into α-tridymite at 1470 ± 10°.[4]

The inversion from α-tridymite into α-quartz at 870 ± 10°).[4]

[1] Therefore, the doctrine, advanced by me in 1908, of the inconsiderable rise of the *melting* point of silicate minerals cannot also, as a general rule, be transferred to the *inversion* point. I refer, on this subject, to the instructive remarks, made by V. M. Goldschmidt, *Die Kontaktmetamorphose im Kristianiagebiet* (1911), p. 112, and by C. N. Fenner, *Jour. of the Wash. Acad. of Sci.* (1912), 2.

[2] See G. Tammann *Krystallisieren und Schmelzen* (1903), and several publications by Roozeboom reviewed in Doelter's *Phys.-chem. Mineralogie* (1905), p. 31.

[3] According to the terminology used by Boeke and by many other mineralogists, I employ α to designate the modification stable at a higher temperature, β and γ to designate the modifications stable at lower temperatures. To avoid misconception, it should be noted that some investigators, among them Wright and Larsen, have employed quite the reverse terminology (α designating lower, and β higher temperature).

[4] C. N. Fenner, *Amer. Jour. of Sci.*, XXXVI (1913).

The inversion from α-quartz into β-quartz at 575 ± 2°.[1]

According to the statement made by A. L. Day, R. B. Sosman, and J. C. Hostetter[2] the specific volume of β-quartz is at 20° 0.3775 (=density 2.649), but rises by heating, and at 561°, or just below the inversion point, it has risen to 0.3922. At the inversion point there is a sudden rise, which, however, is not precisely stated, and then we pass on to α-quartz at 585° with a specific volume of 0.3972.

According to the statements of F. E. Wright and Esper L. Larsen the inversion heat, when β-quartz is transformed into α-quartz, amounts to 4.3 ± 1 cal. If we set the volume difference at the point of inversion at 0.003 and the inversion heat at 4.3 cal., there is a rise of 0.015° per atmosphere, which makes at a pressure of 1000 atmospheres, corresponding to a depth of about 3.7 kilometers, a rise of about 15°. This affords a measure for the order or quantity which has to be taken into account. Accordingly the difference between α-quartz and β-quartz, if depths of more than 5 kilometers are not involved, can, at any rate with only a little modification, be employed as a geological thermometer.

As to the relation of inversion point and pressure between α-quartz and tridymite the case is quite different. At room temperature tridymite has a specific volume of 0.4329 (density = 2.31, medium of 2.282 and 2.326) and β-quartz a specific volume of 0.3775 (density = 2.649); $v_1 - v_2$ accordingly amounts to 0.0554, which is a very high value. By heating, β-quartz, as has just been mentioned, expands its volume considerably and then changes into α-quartz, which, according to the statements of Day, etc., has at 850° a specific volume of 0.3957. According to the law of the expansion of bodies by heating, tridymite also must expand its volume at higher temperature, but how much is not stated. If we estimate its specific volume at 875° at 0.445, the volume difference $v_1 - v_2$ at 875° will amount to 0.05 (or perhaps a little more).

The inversion heat is not stated, but must be supposed to be tolerably low. A rough estimate, rating the inversion heat at 10 and 5 cal., respectively, gives a rise of inversion temperature per

[1] F. E. Wright and E. S. Larsen, "Quartz as a Geologic Thermometer," *Amer. Jour. of Sci.*, XXVII (1909).

[2] *Amer. Jour. of Sci.*, XXXVII (1914).

atmospheric pressure of respectively 0.115 and 0.23°. A corresponding rough calculation has been made by Fenner,[1] who presumed $v_1 - v_2 = 0.057$ (as at room temperature) and inversion heat = 15 cal., which makes a rise of temperature per atmosphere of 0.105°. Starting from these figures (15, 10, 5 cal.) we should have, on a pressure of 270 atmospheres (or at the depth of 1 kilometer), a rise of the inversion point of respectively 28, 38 and 76°, or from 875° to respectively 908, 913 and 951°—and it may be that even the last number is too low an estimate. On the pressure prevailing at the depth of a few kilometers, the inversion point quite certainly will most likely prove to be considerably above 1200°.

The binary eutectics Qu:Or and Qu:Ab, at a pressure of one atmosphere, I estimate at about 1075°–1100°, repectively 975°–1000°. The ternary eutectic Qu:Or:Ab must lie somewhat lower, probably at about 950° or 925°.

If we choose for instance a common granite, quartz porphyry, or rhyolite, the final crystallization must here take place as a complex eutectic Qu:Or:Ab+An, with a little ferric oxide and Mg, Fe-silicate, at a pressure of one atmosphere at a temperature of presumably about 900°-950°. And even if there occurs some surplus quartz, so that the crystallization of this mineral begins at a comparatively early stage, still the first crystallization of SiO_2 will scarcely take place at a higher temperature than 950° or 1000°. These values of temperature reckoned on the pressure of one atmosphere must certainly be increased somewhat, but only a little, for crystallization at great depth and under high pressure, but, as we shall mention later, must be decreased by the content of water, etc., especially in the granitic deep-seated magma.

As, on the other hand, the temperature of the inversion point between α-quartz and tridymite rises so considerably, SiO_2 will never crystallize in deep-seated rocks as tridymite, but always as quartz, and this quartz in granite, quartz-porphyry, and graphic granite is, as pointed out by Wright and Larsen, always an α-quartz.

Tridymite as a primary[2] formation in igneous rocks is, as is well known, limited to certain rhyolites, trachytes, andesites, etc.,

[1] *Jour. of the Wash. Acad. of Sci.*, 2 (1912), p. 479 and *Amer. Jour. of Sci.*, XXXVI (1913), p. 347.

[2] The hydrothermal formation of tridymite is here left out of consideration.

consequently to effusive rocks and to some dike rocks crystallized at a small depth. The crystallizing temperature will here have been above, probably indeed only a little above, the inversion point between α-quartz and tridymite in force at the pressure in question, and accordingly at depths of some hundred m., viz., at about 900° or perhaps a little higher.

By stating the depths at which SiO_2, in the effusives and dike rocks here mentioned, occurs as quartz or as tridymite, our knowledge of the influence of pressure on the rise of the inversion point between α-quartz and tridymite will be increased. Fenner (*Amer. Jour. of Sci.*, XXXVI, p. 348) describes a volcanic rock in which quartz phenocrysts were first formed and were afterward transformed into tridymite. Fenner suggests the explanation that the quartz phenocrysts were formed at higher pressure a little below the inversion point in force at the pressure in question, and that the magma with its phenocrysts was afterwards brought nearer the surface, viz., to a diminished pressure, lying a little above the inversion point at the given temperature. The phenocrysts of α-quartz first formed at the greater depth must consequently now be transformed into tridymite. Fenner, however, expresses some doubt as to this explanation, which, after all, in my opinion, is the natural one.

According to what has been stated by Wright and Larsen, the quartz in the graphic-granite from granite-pegmatites was originally formed as α-quartz, and accordingly at a relatively high temperature, viz., between the inversion point between β- to α-quartz and α-quartz to tridymite. But, besides, there sometimes occurs, in the granite-pegmatites, quartz that "in all probability has never been heated above the inversion temperature between α- and β-quartz." "These large masses of quartz were in certain cases definitely stated by the field relations to be the last portions of the pegmatite to crystallize out." This β-quartz which is formed below the inversion point between α- and β-quartz, and the formation of which, at the enormous pressure, must have taken place at a temperature below 600 or 625°, must be supposed to have been separated from a particular solution of SiO_2+H_2O (see following chapter on the influence of the light volatile compounds).

According to the investigations made at the Geophysical Laboratory in Washington, the inversion point between pure $\alpha = CaSiO_3$ (*pseudowollastonite*) and $\beta = CaSiO_3$ (*wollastonite*) has been stated at about 1200°. Some amount of $MgSiO_3$ entering isomorphously into the silicate makes the inversion point rise; thus about 6 per cent $MgSiO_3$ brings about a rise up to 1300° and 17 per cent $CaMgSi_2O_6$ (= *ca.* 8 per cent $MgSiO_3$) even up to 1345 ± 10° C.[1] The inversion point of the mineral wollastonite occurring in the contact zones, containing as as general rule a little $MgSiO_3$, must, accordingly, be estimated, at the pressure of one atmosphere, at about 1250–1300°, and at a high pressure even a little higher temperature must be presumed, though, on account of the small difference of density between the two forms, the rise will probably be quite inconsiderable.[2]

As will be brought out in a later paper, the *eruption* of the magmas, as a general rule, took place at a temperature which was for the deep-seated rocks almost exactly *identical with the temperature of the beginning crystallization*. For the porphyry rocks we may in many cases assume a temperature of the eruption even somewhat below that of the beginning crystallization.

If we leave out of consideration the peridotites, anorthosites, and analogous anchi-monomineral deep-seated rocks, the *eruption temperature*, accordingly, must only exceptionally have been so high as about 1300°. For many anchi-eutectic rocks, I estimate it at about 1250°, and for granitic rocks, even much lower still, as 1000° or somewhat less. Thus, it is easily explained that in the contact zones there always occurs wollastonite and never pseudowollastonite.

$MgSiO_3$.—According to the investigations made by O. Andersen and N. L. Bowen[3] $MgSiO_3$ has, at usual pressure, no true melting point, as, at 1557°, $MgSiO_3$ is divided into solid Mg_2SiO_4 (forsterite) and liquid. The weight proportion of the two phases is 5.5 per cent

[1] T. B. Ferguson and H. E. Merwin, *Amer. Jour. of Sci.*, XLVIII (1919), p. 165, and the earlier investigations here cited.

[2] White and Larsen, *Amer. Jour. of Sci.*, XXVII (1909), p. 421; cf. V. M. Goldschmidt, "Die Kontaktmetamorphose im Kristianiagebiet" (1911), p. 110.

[3] *Amer. Jour. of Sci.*, XXXVII (1914), and *Zeits. f. anorg.*, Ch. 87 (1914).

forsterite to 94.5 per cent fluid. With continued heating the forsterite dissolves in the course of time, so that all is transformed into fluid at 1577°.

On cooling a melt of $MgSiO_3$ there first crystallizes (at 1577°–1557°) a little forsterite, which on continued (and slow) cooling is resorbed under new formation of solid $MgSiO_3$ (at high temperature clinoenstatite).

The inversion point, at a pressure of one atmosphere, between clinoenstatite and enstatite amounts to about 1100°. The point cannot be settled exactly. The above reference to the treatise of Andersen and Bowen is for pure $MgSiO_3$ (at one atmospheric pressure).

For (Mg, Fe) SiO_3, (Mg, ^{Fe}) SiO_3 and $FeSiO_3$ the following must be taken into consideration:

Mg_2SiO_4 has melting point 1890°.

Fe_2SiO_4 has melting point about 1100°.

For the intermediate mixtures there are intermediate melting point intervals (Fig. 22).

Fe_2SiO_4 and Mg_2SiO_4 with relation about in the middle between Mg and Fe, has a considerably lower melting point interval than 1550°, and consequently cannot be separated in the solid face at the first mentioned temperature from a (Mg, Fe) SiO_3 melt. This makes it probable that the splitting by one atmosphere's pressure of solid pure $MgSiO_3$ into olivine-mineral and fluid may be transferred to (Mg, ^{Fe}) SiO_3 with only a little Fe, but not to metasilicate with predominant Fe or with a middle relation between Mg and Fe.

Clinoenstatite (respectively clinobronzite), as well known, sometimes occurs in meteorites, but has never been determined certainly in terrestrial igneous rocks. If the metasilicate in the rocks originally had existed in the clino-modification (clino-enstatite, -bronzite, -hypersthene) we might, according to the experiences from the meteorites, suppose that the original mineral, in any case, occasionally would still have been in existence. But while this, as far as we know up to date, never is the case, the explanation seems to be that the crystallization of the Mg, Fe-metasilicate in the common igneous rocks—of composition between 0.08 $FeSiO_3$, 0.92 $MgSiO_3$ and about 0.4 $FeSiO_3$, 0.6 $MgSiO_3$—always took place

for the existing pressure at a temperature lower than the inversion point between the clino- and the ortho-modification of the metasilicate. This view is strengthened by the fact that in the rocks where the metasilicate has crystallized at an early stage it shows the crystallographic contour of the orthopyroxene.

It is probable that the inversion temperature between the clino- and the ortho-modification rises not quite inconsiderably with the pressure. The difference in density between clinoenstatite and enstatite is indeed very little, but if the inversion heat is minimal, as only a small fraction of 1 cal., the inversion temperature will nevertheless increase not inconsiderably with the pressure. In the common anchi-eutectic norites, etc., the crystallization interval for the most part lies at about 1275–1200°, which must be lower than the inversion boundary at high pressure between the two Mg, Fe-metasilicate stages. In bronzite rocks and bronzite-carrying olivine rocks a not inconsiderably higher crystallization interval may be presumed, but even in these rocks we cannot observe any structural indication that here originally occurred a clino-modification.

By melting $MgSiO_3$ at 1557° to a liquid in connection with solid olivine—the latter only in a small quantity—and at 1577° only to a liquid, $v_1 - v_2$ will, in accordance with what happens in all previously examined silicates, doubtless be positive. That is to say, the "incongruent" melting point of $MgSiO_3$, in the same way as of other silicates, must be supposed to rise somewhat with the pressure. The splitting of $MgSiO_3$ to an olivine (very poor in FeO) in the igneous rocks might thus have taken place at a temperature somewhat above 1557°. But the crystallization of the hypersthene-bearing gabbros, syenites, granites, etc., occurred, as just mentioned, at a considerably lower temperature. The conclusion of this, according to my view, is that the proved crystallization of forsterite in a melt of $MgSiO_3$ at a pressure of one atmosphere cannot be transferred to take place at the crystallization of the bronzite- or hypersthene-bearing deep-seated rocks. I cannot agree with more of the opinions maintained by Andersen and Bowen (*loc. cit.*) and Bowen[1] since these investigators have not taken into consideration the influence of pressure.

[1] The crystallization of haplobasaltic and haplodioritic magmas (1915), and The later stages of the evolution of the igneous rocks (1915).

As an argument for the primary crystallization of olivine with following resorbtion of olivine under new-formation of orthopyroxene, several investigators have referred to the well-known kelyphitic or coronation zones around olivine, with hypersthene in the inner zone facing the olivine. As stated above (Vol. XXIX, pp. 645–49) we are dealing here, however, with a reaction in the *solid* face between olivine and plagioclase at a maximum temperature of about 1250°–1200° and generally somewhat lower—thus at least 300° lower than the temperature (1557°) at which, under a pressure of one atmosphere, olivine may crystallize from a melt of $MgSiO_3$. The kelyphitic hypersthene zone next to the olivine may thus have nothing to do with the primary segregation of olivine from a melt of $MgSiO_3$ and the later transformation from olivine to orthopyroxene.

As maintained by Andersen (*loc. cit.* [1915], p. 453) the olivine, as a consequence of the splitting of $MgSiO_3$, in the orthopyroxene-bearing igneous rocks, should in every case have crystallized earlier than the orthopyroxene, and the crystallization of the olivine should have been finished even before the beginning of the solidification of the orthopyroxene. But petrographic investigation of rocks rich in orthopyroxene but poor in olivine, shows that this is not so. We refer to the facts mentioned above (Fig. 25).

The conclusion from this is that bronzite and hypersthene, under high pressure, in the common deep-seated magmas (norites, etc.), crystallized directly from the magma in the same way as the other common silicate minerals. How it may be with enstatite in an almost pure $MgSiO_3$ magma, remains, however, an open question. In the igneous rocks, indeed, we never find orthopyroxene with less than *ca.* 7 per cent $FeSiO_3$ (or more than 93 per cent $MgSiO_3$).

C

1. Many minerals, such as olivine, monoclinic pyroxene, the feldspars, spinel, magnetite, etc., may be formed in melts at a pressure of one atmosphere, as well as in effusives and in deep-seated rocks—consequently at low, as well as at middle high, and very high pressure.

2. Some minerals, as *melilite* for instance, which crystallize out of melts at a pressure of one atmosphere, occur, moreover, in effusive rocks (melilite basalts, etc.) and in certain dike rocks (as

alnöite), but on the other hand are not—as yet (1920)—known from deep-seated rocks.

If we compare a number of analyses of troctolite ("forellenstein" and feldspar-peridotites) with for instance the analyses of slags given in my work "Silikatschmelzlös," I, p. 16 (containing *ca.* 30–42 per cent SiO_2, 8–28 per cent AlO_3, 20–40 per cent CaO and up to 13 per cent MgO with some FeO, MnO, etc.), in which a melilite mineral (melilite-gehlenite) is crystallized, it is apparent that by re-melting at one atmosphere some of the deep-seated rocks mentioned, which consist only of olivine and anorthite-bytownite, they must recrystallize with more or less melilite besides several other minerals of which one is spinel (Vol. XXIX, p. 524).

Gehlenite occurs in some contact zones; it must consequently under certain conditions be formed at high pressure. And melilite occurs, as just mentioned, as a rarity in some dike rocks, which might have been solidified at a tolerably great depth, thus also at a tolerably great pressure.

It is worth noticing, however, that melilite, so far as known, is lacking in the common deep-seated rocks, and especially that, instead of a melilite mineral, we find in the troctolites the combination olivine and anorthite-bytownite.

A similar case is that of *leucite* which can crystallize in melts at a pressure of one atmosphere, and which occurs in many effusive and some dike rocks, but has only rarely been found in deep-seated rocks. When microcline and biotite are melted together in certain proportions, leucite results. And in many deep-seated rocks which by re-melting at one atmosphere would give leucite, we find instead of leucite other minerals, as microcline, biotite, etc.

3. On the other hand there are some minerals which in part preferentially and in part exclusively belong to deep-seated or other rocks formed at a very high pressure. As an instance we may choose *garnet*.

By re-melting garnet there results, as is known, not this mineral, but a mixture of other minerals, according to the composition of the garnet—melilite, anorthite, olivine, spinel, etc. On the other hand, we may get garnet by using certain chlorides, for instance $AlCl_3$, as the solution medium. Garnet—or at least some varieties

of garnet—may thus also be formed under high temperature at the pressure of one atmosphere.

Garnet occurs as a primary formation in some effusives and often in various deep-seated rocks. The mineral further is formed as known *inter alia* by contact-metamorphism and by intensive dynamo-metamorphism.

Amphibole, as is known, does not crystallize from anhydrous silicate melts at one atmosphere but it is generally supposed to be conditioned by high pressure. This depends rather certainly on the fact that the magmas only at high pressure may carry the sufficient quantity of water (or hydroxyl) which seems to be a constitutional component of amphibole.

Biotite has, as is known, been produced synthetically by melting with fluorides, and the magnesia-mica *phlogopite* has also been established as crystallized out of common anhydrous slags containing a little fluorine.[1] Phlogopite may thus be formed by crystallization of silicate melts at a pressure of one atmosphere. But common mica occurs in the igneous rocks preferentially in deep-seated rocks; it occurs also, however, in effusives. On the other hand, muscovite never occurs as a primary mineral in effusives, but occurs in certain granites and especially in granite-pegmatite dikes.

As we shall show later, in granites of exactly the same composition—excluding the original content of H_2O, etc.—hypersthene, biotite or muscovite may crystallize. Which of these three minerals is formed, may depend on the content of H_2O, etc., in the magma (when least, hypersthene is formed; when most, muscovite).

[1] See my cited treatises from 1884–85 and 1888–90. In slags from the Kafveltorp copper works (containing 41–46 per cent SiO_2, 8–11 Al_2O_3, 7–15 FeO including *ca.* 0.5 Fe_2O_3, 13–20 CaO, 10–18 MgO, a little ZnO, Cu_2S, etc., also 3–5 K_2O+Na_2O and a little F) there has crystallized 10–15 per cent mica, in great leaves up to 5–6 mm. in diameter, with the following characteristics: pseudohexagonale thin leaves, with just as good cleavage as natural mica; elastic flexible; pressure figure as in natural mica; prism angle *ca.* 121°; optical biaxial and negative; acute bisectrix almost perpendicular on 001, differing only by 1–1.5°; 2 V only a very few degrees; colorless; very vivid interference colors; very resistent to acids; chemical composition: 42.20 SiO_2, 11.30 Al_2O_3, 5.92 FeO (with a little Fe_2O_3), 22.93 MgO, 2.29 CaO, 1.40 ZnO, 0.33 Cu_2S (mechanical), total 86.37 per cent, rest *ca.* 13 per cent K_2O, Na_2O and F. The mineral is thus a MgO-mica rather poor in FeO and Fe_2O_3, viz., a phlogopite, whose content of H_2O (or HO) is replaced by another component, F.

The influence of pressure with regard to the minerals amphibole, biotite, and muscovite must then be indirect, since the formation of these minerals depends essentially on the magmatic content of H_2O, etc., which further, to a certain extent, depends on the pressure.

By great differences in pressure, H_2O content, etc., a magma otherwise of the same or almost the same chemical composition may give rise to the crystallization of totally different minerals or combination of minerals. P. Niggli, in his work (1920, p. 207) cited below, mentions as a typical instance of this the two rocks, (1) a durbachite (rich in biotite and hornblende and further orthoclase, plagioclase, a little quartz and titanite bearing boundary facies of granite), and (2) a glassy leucite basalt.

	1. Durbachite	2. Leucitebasalt
SiO_2	51.05	51.43
TiO_2	1.76	1.12
Al_2O_3	14.49	14.88
Fe_2O_3	4.16	6.30
FeO	4.37	3.14
MgO	8.16	6.67
CaO	5.11	5.01
Na_2O	1.85	1.83
K_2O	7.25	9.22
P_2O_5	0.70	0.51
H_2O	1.05	0.74
Total	99.94	100.85

1. Durbachite from Durbach, Schwarzwald. A. Sauer, *Mitt. Badische Geol. Landesanst.*, II, 1892 (1890). 2. Leucitebasalt from Gaussberg, Kaiser Wilhelm II Land. R. Reinisch, Deutsche Südpol-Exposition II (1), 1906.

Undoubtedly, on account of the high content of water, biotite and hornblende, and further orthoclase, have been formed in the durbachite, while on the other hand in leucite basalt which solidified at lower pressure leucite was formed instead of orthoclase and K_2O-rich biotite.

RS dissolved in silicate melts crystallizes at a pressure of one atmosphere as monosulphid (oldhamite, alabandine, sphalerite, pyrrhotine or troilite, etc.), but may at high pressure by pneumatolytic processes (in the crystallization of magmas as described by Brögger[1]

[1] *Zeits. f. Kryst. Min.*, XVI (1890), I, p. 161.

for the nepheline syenite-pegmatite dikes, further in contact zones, etc.), give rise to the formation of helvine (and danalite). At a moderately high pressure also some double-compounds of silicate and NaCl or Na_2SO_4 (sodalite, nosean and häuyn) crystallize. But these minerals—and according to my experience this is also true of scapolite—may not be reproduced by melting the respective silicate with admixture of NaCl or Na_2SO_4 at common low pressure.

In this connection it may be further mentioned that the magmatic crystallization of minerals as FeS_2 and $CaCO_3$ imply a high pressure.

This review proves that the formation of many minerals, or combinations of minerals, may take place at low pressure as well as at moderately high or very high pressure, and further, that the *determinations undertaken at one atmosphere pressure in regard to the eutectics and mix-crystal systems, so far as these minerals are concerned, may also be made valid with only slight corrections at high pressures,* even at the high pressure prevailing during the crystallization of the deap-seated magmas.

But this may not be applied to all minerals, or combinations of minerals. The formation of some minerals, as melilite and leucite, is favored by low pressure; the formation of other minerals, as garnet, is favored by high pressure. For some minerals, as especially muscovite, further H_2O-bearing biotite and hornblende, a more or less high pressure may be an indispensable condition for crystallization from the magma; indeed indirectly depending on the fact that the presence of sufficient H_2O in the magma implies a high pressure. For pyrite and calcspar, which at one atmosphere are dissociated by moderate heating, high pressure is necessary for their crystallization from the magma.

It is to be noted that *garnet* has a much *higher* density (Mg-Al_2–garnet 3.7–3.8, Ca-Al_2–garnet 3.9–4.0, Ca-Fe_2–garnet 3.8–4.1, etc.) than the combination of those minerals which result from re-melting it at one atmosphere. On the other hand, *leucite* has a much *lower* density (2.45–2.50) than the combination of those minerals, especially orthoclase (2.55) and the various K_2O-rich micas (2.76–3.0) which generally replace leucite in the deep-seated magmas. And *melilite* (2.90–2.93) has somewhat *lower* density than the combina-

tion of a medium mixture principally of olivine (3.22) and anorthite (2.765) which in most cases replace it in the deep-seated rocks.

In all of these three cases we thus observe the fact that a combination of minerals, respectively a single mineral (leucite, melilite) in the effusives are replaced in the deep-seated rocks by a single mineral (garnet), respectively a combination of minerals, characterized by *increased* density.

This recalls the well known "volume law" valid for dynamometamorphism, viz., that various minerals under high pressure form new combinations with the minimum total volume—a law whose physicochemical cause, moreover, is not exactly elucidated.

Since the above section, in the main, was written, in the winter 1919–20, a treatise on "The Mineral Facies of Rocks," by P. Eskola,[1] was published, wherein he tries to establish some (five) facies for the mineral combinations depending on the pressure not only for the metamorphic, but also for the igneous rocks. Eskola classes with the last, the facies of the igneous rocks formed under the highest pressure, among others those especially investigated by him, namely garnet-rich (with up to 75 mol. per cent pyrop-component $Mg_3Al_2SiO_3O_{12}$) eclogites, which "occupy a volume about 15 per cent smaller than that of the corresponding gabbros." Eskola thus maintains the same views as those I have pointed out above. I call attention to this treatise, in which are given some new instances of the interdependence of the formation of certain mineral combination in the igneous rocks upon the pressure. Further on Eskola treats of the interdependence of the metamorphic new-formations upon the pressure, which matter I do not touch in this treatise.

[*To be continued*]

[1] *Norsk geol. Tidsskrift*, Vol. VI (1920).

EDITORIAL

There has come to the editors of this *Journal*, Volume 1, Number 1, of the Japanese *Journal of Geology and Geography*, issued under the auspices of the National Research Council, Department of Education, Japan. The journal is published in Tokio and will be issued as a quarterly. The *Journal of Geology* extends to this new confrère in the service of the earth sciences its hearty congratulations and good wishes. For a number of years Japan has been sending many of her young geologists to the United States for their special training, and the associations thus established have been mutually pleasant and profitable. The appearance of this journal, published in English, will extend and strengthen the comradeship in science between Japan and the United States and with all other English-speaking countries. The new journal consists in part of original contributions and in part of abstracts of articles appearing in other Japanese publications. Many of these cover articles originally published in Japanese that would not otherwise be utilizable by English-speaking readers. Many of the abstracts are prepared by the authors, and others come from such authoritative reviewers as Takeo Kato, well known to American geologists. While most of the abstracts are in English, one of them is in German.

E. S. B.

Petrological Abstracts and Reviews

ALBERT JOHANNSEN

Miller, William J. "Geology of the Blue Mountain, New York, Quadrangle," *Bull. 192, N. Y. State Mus.*, 1916 (1917). Pp. 68, map 1, pls. 11, fig. 1.

The Blue Mountain Quadrangle in the Adirondack region lies in northern Hamilton County, N. Y. From oldest to youngest, the formations are: the Grenville series, limestones, and quartzites, followed by two small intrusions of anorthosite. The most widespread rocks of the region are syenite and granite with basic phases which are intrusive into both the Grenville series and the anorthosite. Following this came gabbro, still later pegmatite and a few dikes of diabase. Glacial and postglacial deposits complete the series. The rocks of the Grenville series are thought to be sedimentary. Twelve quartz-syenites are described, three of which are said to be "practically monzonites." The quartz ranges from 12 to 20 per cent, consequently the reviewer would prefer not to call them quartz-syenites, which name he would limit to syenites with less than 5 per cent quartz, but granites. In the reviewer's system ten of these rocks are classed in 226′, granites (or in limited sense monzo-granites), the remaining two are 226″ or quartz-monzonites. The basic phases of the syenite are 228, 328, 227″, 2212, 3211′, tonalites, quartz-monzonite, diorite, and monzo-diorite. Of fifteen granitic-syenites and granites, thirteen are 226′ (granites), one 126′ (a leuco-granite), and one near Daly's Moyie sill rock, at the intersection of Families 1, 2, 5, and 6′, in Class 2, Order 2. Of six "typical gabbros," one (No. 17) is a garnet-bearing melagabbro, and one (No. 52) is a garnet-bearing norite. The other four are said to contain oligoclase-labradorite and andesine-labradorite which, without further descriptions of the feldspars, prevents their classification.

Miller, William J. "Adirondack Anorthosite," *Bull. Geol. Soc. Amer.*, XXIX (1918), 399–462, figs. 3.

Miller takes exception to Bowen's statement (*Jour. Geol.*, XXV [1917], 242) that "Anorthosites are made up almost exclusively of the single mineral plagioclase." Bowen's statement is and is not true, depending upon whether the rock anorthosite or the anorthosite formation is meant. Hunt's original definition applied to a whole series of rocks which are "composed chiefly of a lime-soda feldspar, varying in composition from andesine to anorthite, and

associated with pyroxene or hypersthene. This rock we shall distinguish by the name of anorthosite. . . . . In some cases the . . . . dark mineral is entirely wanting." (*Geol. Canada*, 1863, 22.) According to modern petrographic usage the term anorthosite has come to mean a basic-feldspar rock, which is practically free from dark minerals, say with less than 5 per cent, yet the Canadian anorthosites are spoken of in the sense of Hunt. Bowen, therefore, if he speaks of the whole formation, is incorrect when he says that "Anorthosites are made up almost exclusively of the single mineral plagioclase," for as Miller shows, the dark mineral averages 10 per cent. He says, "The main bulk . . . . contains 5 to 10 per cent of minerals other than plagioclase . . . . in many places there are 10 to 20 per cent, or even more of dark mineral. It is also true that some portions of the mass contain less than 5 per cent of dark minerals. . . . . Conservatively estimated, I believe the average . . . . anorthosite carries fully 10 per cent of minerals other than plagioclase." Attacking Bowen's theory that the anorthosite may not have been at one time in a molten condition, Miller says: "The Adirondack anorthosite would have formed a melt of notably more complicated composition than the artificial melt with 10 per cent diopside and [it would have been formed] under deep-seated geologic conditions. Is it safe to say, therefore, that such a melt may not have been a true magma with a high percentage of liquid? . . . . Another important consideration is the almost certain presence of very appreciative amounts of dissolved vapors, particularly water vapor, in the magma. . . . . Also the presence of about 2 per cent iron oxide in the typical anorthosite should not be overlooked. . . . . All things considered, therefore, I not only think it very reasonable to apply the mutual solution theory to the anorthosite, but also to regard the anorthosite to have existed in magmatic condition at a moderate temperature." He says further: "I consider the main steps in the development of the anorthosite to have been as follows: First, intrusion of a laccolithic body of gabbroid magma . . . . second, relatively rapid cooling of the marginal portion to give rise to the chilled gabbroid border phase; and, third, settling of many of the slowly crystallizing femic minerals in the still molten interior portion of the laccolith, leaving a great body of magma to gradually crystallize into anorthosite. Thus, at the bottom, and probably nowhere visible in the field, lies a mass of pyroxenite or peridotite . . . . " (p. 457).

Miller says in reference to a syenite (p. 438), "Labradorite and andesine are always present and oligoclase usually." The reviewer must again make the statement which he has made a number of times before, that he doubts whether in rocks which are composed of crystals of a single generation, two different plagioclases can occur together except as zonal growth.

It is impossible in this abstract to give all of Miller's conclusions. Briefly they are:

The Adirondack anorthosite is a great laccolithic intrusive body—older than the accompanying granite-syenite series. The average rock contains fully 10 per cent of dark minerals, and is differentiated practically *in situ* from

an intruded gabbroid magma, developing a chilled gabbroid border facies and an upper zone of anorthosite from a magma which was to a very considerable degree at least, actually molten. The anorthosite-gabbro and gabbro associated with the anorthosite represent local differentiates. Syenite and granite are not differentiates from the anorthosite, although transition rocks (Keene gneiss) were produced locally by magmatic assimilation of still hot, but not molten, anorthosite by the syenite or granite magma.

MILLER, WILLIAM J. "Geology of the Schroon Lake Quadrangle," *Bull. 213, 214, N. Y. State Mus.*, 1918 (1919). Pp. 102, map 1, pls. 14, figs. 9.

The Schroon Lake quadrangle represents an area of about 215 square miles in the central eastern portion of the Adirondack mountain region. The oldest rocks are those of the Grenville series which were intruded by a relatively stiff gabbroid magma which differentiated and formed the anorthosite. The intrusion of the anorthosite lifted the Grenville strata but also engulfed fragments of it. Following this came the intrusion of the syenite-granite series which partially domed, partially broke and tilled, the Grenville. The metamorphism of the Grenville took place probably before or during the period of igneous activity. During the succeeding period of uplift there was great erosion and some igneous activity indicated by the intrusion of certain diabase dikes. In late Cambrian time a gradual submergence took place with deposition of sandstones and dolomites. A long period of erosion from Ordovician to late in the Mesozoic reduced the land to a peneplain rising to moderate heights above the general level, and this was followed by uplift and active erosion, which continues to the present time. During the Ice Age the entire area was covered by the ice sheet. Toward its close there was a subsidence of several hundred feet below the present level, and finally a differential uplift with greater elevation at the north.

MILLER, WILLIAM J. "Banded Structures of the Adirondack Syenite-Granite Series," *Science*, XLVIII (1918), 560–63.

Both assimilation and differentiation contributed to the banding.

MILLER, WILLIAM J. "Silexite: A New Rock Name," *Science*, XLIX (1919), 149.

The name silexite is proposed for any body of pure or nearly pure silica of igneous or aqueo-igneous origin which occurs as a dike, segregation mass, or inclusion within or without its parent rock. (See also "Pegmatite, Silexite, and Aplite of Northern New York," *Jour. Geol.*, XXVII [1919], 28–54.)

MOORE, E. S. "'Pele's Tears' and Their Bearing on the Origin of Australites," *Bull. Geol. Soc. Amer.*, XXVII (1916), 51–55.

Australites are thought to be of volcanic origin since bodies of distinctly volcanic origin show that similar forms can originate in the atmosphere from rotating liquid bodies.

MOORE, RAYMOND C. "The Relation of the Buried Granite in Kansas to Oil Production, *Bull. Amer. Assoc. Petroleum Geol.*, IV (1920), 255–61.

This paper is petrographically of interest from the short description of a buried ridge of granite extending as an elongated mass from north of the Nebraska state line into Kay County, Oklahoma. The ridge reaches its highest elevation near the north boundary line of Kansas in Nemaha County, where it is less than 500 feet below the surface. It descends gradually to the south and forms a saddle in northwestern Wabaunsee County, then rises in Morris and Chase counties in underground peaks of different elevations.

O'HARRA, CLEOPHAS C. "A Bibliography of the Geology and Mining Interests of the Black Hills Region," *South Dakota School of Mines Bull.*, XI, 1917. Pp. 216–17, map 1.

A very important and useful bibliography of the Black Hills, containing not only titles and references, but abstracts of each of the 1,187 items listed.

OSANN, A. "Der chemische Faktor in einer natürlichen Klassifikation der Eruptivgesteine, I." *Abhandl. d. Heidelberger Akad. d. Wiss., Math.-naturw. Kl.*, Abh. 8, 1919. Pp. 126, pls. 5.

This is another important contribution to the chemical classification of rocks, and one which will be welcomed by everyone who uses Osann's system. In former publications the determination of the *s*, *A*, *C*, *F*, *a*, *c*, and *f* values, and their plotting in triangular diagrams ended the attempt at classification. Here regular pigeonholes are established, so that it is a very simple matter to locate analyses of similar rocks. The first 23 pages of this work are devoted principally to general discussions and various modifications of the previous methods of calculation. It is to be regretted that nowhere is there given a definite set of revised rules for the computation of the formulae. The various modifications here proposed can be adopted by those already familar with the system, but a beginner will find it necessary to follow the discussion through many pages of print to obtain for himself a workable set of rules. It is true that the system has gradually developed, and various changes have been introduced, but it would seem that it is now in such form that well-defined rules could be given, and it is to be hoped that in the near future Professor Osann

will publish such a set. From page 23 to the end various type rocks are calculated and the relations between their mineral composition and their position in the classification are discussed. The general divisions of the new groups are as follows:

	c=0–0.5	c=1–2	c=3–4	c=5–6	etc., etc.	c=13–14
a=30 –28						
a=27 –25						
a=24 –22						
etc., etc.						
a= 9 – 7						
a= 6 – 5						
a= 4 – 3						
a= 2 – 1						
a= 0.5– 0						

The values of *a* have intervals of 3 between 30 and 7, from 6 to 1 the interval is 2: the values of *c*, except the first, have intervals of 2.

The limiting values of the older rock types are:

Rock Type	Limiting Values			
	s	*a*	*k*	Percentage SiO_2
Granite and Quartz-diorite	82.5–69	26–27	1.8 –1.2	63
Syenite and Diorite	74 –57	24–23	1.1 –0.9	65–51
Essexite and Gabbro	60 –47	12– 0	0.9 –0.7	53–46
Mafic Essexite and Gabbro, Hornblendite and Pyroxenite	46 –42	2– 0	0.7 –0.6	44–42
Dunite, Peridotite, and basic Hornblendite	41 –36	2– 0	0.6.–0.5	40–35
Nephelite-syenite	67 –63	26–13	0.8 –0.7	59–54
Theralite and Shonkinite	53 –49	12– 5	0.65–0.5	46–43
Alkalic feldspar-free Rocks	58 –46	26– 3	0.86–0.39	50–39
Anorthosite	65 –50	11– 1.5	1.0 –0.9	57–44

The first three groups included the acid, neutral, and basic igneous rocks. According to Rosenbusch, the acid have 65 per cent, the neutral between 64 and 52 per cent, and the basic below 52 per cent of SiO_2. The fourth and fifth groups, with their extrusives are mafic, basic, and ultra basic differentiates of the third group. The sixth group is an alkalic side-group of the second, the seventh of the third. The eighth group includes rocks of very different mineralogical character and can be regarded only as a basic side-group of the sixth and seventh. The last group is connected with the second and third but belongs to the alkali series.

OSANN, A. "Der chemische Faktor in einer natürlichen Klassifikation der Eruptivgesteine, II," *Abhandl. d. Heidelberger Akad. d. Wiss., Math.-naturw. Kl.*, Abh. 9, 1920. Pp. 59.

In the first part, reviewed above, the plutonic rocks are discussed; in this the extrusives are considered. One hundred and fifty-one types, based on 973 analyses, are given, but owing to present conditions of publication, only the type rocks are shown, and the number of analyses falling in each group is indicated. The tabulation follows that given for the plutonites.

PATTON, HORACE B. "Geology and Ore Deposits of the Platoro-Summitville Mining District, Colorado," *Bull. 13. Colo. Geol. Surv.*, 1917. Pp. 122, maps 3, pls. 40.

The region here described lies between Creede, Alamosa, Chama, and Pagosa Springs. The rocks which occur are very similar to those described in the folios of the San Juan region. Short descriptions are given of rhyolite, latite (two chemical analyses), andesite (one analysis), basalt, monzonite (one analysis), quartz-monzonite-porphyry and diorite.

PETROGRAPHIC COMMITTEE. "Report on British Petrographic Nomenclature," *Mineralog. Mag.*, XIX (1921), 137–47.

A committee, consisting of Watts, Elsden, Flett, Teall, Thomas, Tyrrell, Evans, Hatch, Holmes, Prior, Rastall, and Smith, from the Geological Society of London and the Mineralogical Society, report on ninety rock-names and petrographic terms which have been used in more than one sense by British authors, and make recommendations as to those which are to be rejected and definitions of those to be retained. Some of the recommendations are in direct opposition to the recommendations by the Committee on Petrographic Terms of the U.S.G.S. in 1897 and 1898. For example the British committee recommend the use of the terms porphyry and porphyrite in the sense used in Germany, namely porphyry for rocks with dominant alkali-feldspar and porphyrite with dominant plagioclase. The U.S.G.S. recommended that "Porphyry and its derivatives are to be used as purely textural terms, without limitation to mineralogical groups. Porphyry will thus apply to all rocks, whatever their composition, containing phenocrysts in a distinct groundmass, and without regard to the size of the grains of the groundmass. Porphyrite is discarded as superfluous. . . . . " Further in regard to the use of the hyphen, the U.S.G.S. recommends that only similar terms be hyphenated, thus two mineral terms or two rock terms, as biotite-muscovite granite, granite-syenite, etc., but mineral and rock, or rock and texture, as unlike terms, are not united. The British committee say: "When a mineral-name, or names,

and a rock-name are compounded to form a name of 'specific' signification, these should be joined by a hyphen; e.g. biotite-granite." With the usage of porphyry in the sense of the U.S.G.S., porphyritic rocks are defined as granite porphyry, diorite porphyry, etc., but the British committee says, "The name granite-porphyry is ambiguous, and should not be used." Why ambiguous is not clear, unless it is thought possible that it may be confused with porphyritic granite. But porphyritic granite and granite prophyry are quite different things. It is recommended that adamellite be discarded, or only used for acid members of the monzonite series, and monzonite is to be restricted to rocks of the type occurring in the Monzoni district. If monzonite is used in the original sense of de Lapparent for the Monzoni rocks, it is a collective name and embraces monzonites Brögger, gabbros, and pyroxenites. Personally the reviewer would like to see the intermediate rocks, monzonite and adamellite, dropped (see *Jour. Geol.*, XXVII [1919], 38, and XXVIII [1920], 229), and the term granodiorite returned to its original sense (*Jour. Geol.*, XXVII [1919] 168). The latter recommendation is also made by the British committee. The usage of the term panidiomorphic by the British committee (following Rosenbusch) as given in the definition of aplite, is regarded by the reviewer as incorrect. A panidiomorphic rock would be one in which all of the constituents have their own crystal boundaries. Such a rock is almost inconceivable: and the texture of aplite is as far removed from this as it can possibly be, for it has a saccharoidal texture, that is, one in which all of the constituents are xenomorphic (allotriomorphic); it is, consequently, panxenomorphic or panallotriomorphic. The British committee recommend the terms allotriomorphic and idiomorphic in preference to xenomorphic and automorphic. The latter, however, have priority by one year. The term essexite "is retained for rocks practically identical with, or which show but slight divergence from, the original type of Salem Neck, Essex Co., Massachusetts," which is a large order since the original locality shows such a divergence of type. It is recommended that diabase be dropped and dolerite used. One is as bad as the other. Diorite and gabbro are given the meanings accepted in the United States (namely separated on the basis of the feldspar), and Harker's usage is not followed. Leuco- as a prefix for leucite, as used by Lacroix, is put in the discard. The less exact terms basic, intermediate, and acid are used in preference to subsilicic, mediosilicic, and persilicic of Clarke.

POWERS, SIDNEY. *A Lava Tube at Kilauea.* Private Publication. Pp. 7, pls. 5.

Describes a lava tube, extending from the Kaluaiki pit crater in a northeasterly direction for 1,494 feet with a drop of 73 feet. The maximum height is 20 feet, the maximum width 22 feet. In the roof of the tube there are more than a dozen small, conical cupolas "blow-piped" by gas escaping from the lava. These cupolas vary from 1 to 8 feet in height and with similar basal diameters. Thirty-three cross-sections, drawn to scale, are given.

POWERS, SIDNEY. "Volcanic Domes in the Pacific," *Amer. Jour. Sci.*, XLII (1916), 261–74, figs. 5.

Gives data on various volcanic domes, showing size, composition, and important features. Viscosity is the principal factor which determines whether the magma shall appear as a flow or dome. In some cases a flow comes first, then a dome; in others the dome comes first and the lava later breaks through the crust.

POWERS, SIDNEY. "Granite in Kansas," *Amer. Jour. Sci.*, XLIV (1917), 146–50.

An earlier report on the granite ridge mentioned above (Moore, Ramond C., *Bull. Amer. Asso. Petro. Geol.*, IV, 1920).

QUENSEL, PERCY. "De kristallina Sevebergarternas geologiska och petrografiska ställning inom Kebnekaiseområdet," *Geol. Fören. Förhandl.*, XLI (1919), 19–52, figs. 15, pls. 2, profile 1.

Describes the crystalline schists from Kebnekaise, in Lapland. An analysis of a feldspar-rich "gneiss-mica-schist" is given.

QUENSEL, PERCY. "Zur Kenntnis der Mylonitbildung, erläutert an Material aus dem Kebnekaisegebiet," *Bull. Geol. Inst. Upsala*, XV (1916), 91–116, pls. 4.

The mylonites from Kebnakaise are regarded as primarily derived from igneous rocks, though some sediments may occur among them.

QUENSEL, PERCY. "Über ein Vorkommen von Rhombenporphyren in dem präkambrischen Grundgebirge des Kebnekaisegebietes," *Bull. Geol. Inst. Upsala*, XVI (1918), 1–14, pl. 1.

Describes a rhombic porphyry in which the feldspar is a microcline antiperthite ($Or_1Ab_9An_2$). It is microperthitic and zonal, with a central portion of plagioclase surrounded by pink potash feldspar or white albite. The change from center outward is not gradual, but abrupt, and seems to indicate a sudden change in the chemical character of the magma.

QUIRKE, TERENCE T. "Espanola District, Ontario," *Mem.* 102, *Canadian Geol. Surv.*, 1917. Pp. 92, map 1, pls. 6, figs. 8.

The Espanola district is 43 miles west of Sudbury, and comprises an area of 116 square miles. The rock formations are principally Huronian, with older metamorphosed sedimentary schists and slates, and intrusive greenstones and granite. The Huronian rocks are cut by diabase dikes and sills, more or less

contemporaneous with the faulting of the region. Pleistocene formations lie directly upon the Pre-Cambrian, and consist of fluvioglacial deposits, till, clays, and lake sands.

QUIRKE, TERENCE T., and FINKELSTEIN, LEO. "Measurements of the Radioactivity of Meteorites," *Amer. Jour. Sci.*, XLIV (1917), 237–42.

Gives the radium content of twenty-two meteorites not previously determined. It is found that the average stony meteorite is considerably less radioactive than the average igneous rock, probably less than one-fourth that of an average granite, and that the metallic meteorites are almost free from radioactivity.

REINHEIMER, SIEGFRIED. *Der Diorit vom Buch bei Lindenfels im Odenwald mit einem Anhang über einige mikroskopische Methoden.* Inaug. Dissert., Heidelberg, 1920. Pp. 63, Figs. 8, Photo. Pl. 3.

Two "diorites" and a gabbro are described. No modal percentages are given, but in general it may be said that the main rock from the Buch consists of more amphibole than plagioclase with accessory biotite and a little quartz. The plagioclase is zonal with cores $Ab_{12}An_{88}$ and outer zones Ab_{40-46} An_{60-54}. There is a pale to colorless amphibole and one that is green, the latter usually surrounding the former. The author says a "gabbro tendency" is shown, and that diallage is proxied by an amphibole of similar chemical composition. The second rock, from Kreuzer's quarry, near Winterkasten, is similar, although generally the amphibole and plagioclase are in equal amounts. The feldspar is approximately $Ab_{17}An_{83}$, biotite is rare, and quartz is wanting. The third rock from near Laudenau differs from the other two. It is described as a gabbro of the type of the Scandinavian hyperites. The dark minerals consist of green amphibole poikilitically intergrown with plagioclase, and diallage and olivine. The plagioclase is Ab_9An_{91}. Since the plagioclase in all of the rocks is labradorite to bytownite, the reviewer would call all the rocks gabbro (amphibole gabbro) in spite of the statement of the author that the magma must have been poor in lime. (No chemical analyses are given.)

Associated with these rocks are certain diaschistic rocks, among them diorite-pegmatite, schlieren of "needle-diorite," and beerbachite.

In the Appendix the determination of refractive indices in cleavage fragments of amphibole by the immersion method, and the determination of 2V with the Federow stage are discussed.

RICHARDS, H. C. "The Building Stones of Queensland," *Proc. Roy. Soc. Queensland*, XXX (1918), 97–157, pls. 3, figs. 10.

The physical, chemical, and mineralogical characters of various available building stones, with their good and bad qualities, and a list of structures with the stones used, are given.

RICHARDS, H. C. "The Volcanic Rocks of Springsure, Central Queensland," *Proc. Roc. Soc. Queensland*, XXX (1918), 179–98, pl. 1, figs. 6.

The oldest rocks of this area are Paleozoic sediments, consisting of sandstones, gravels, and shales, and some limestone. The volcanic rocks, with a total thickness of 1,000 feet, are divided into three groups: a Lower Series which consists of basaltic agglomerate and basaltic flows, followed by trachyte tuffs and flows, then a return to basaltic flows. The Middle Volcanic Series consists of trachytic tuffs and flows which are "really phonolite in the strict petrological sense." In the weathered material, precious opal has been obtained. The Upper Volcanic Series consists of basaltic flows to a thickness of 600 feet. Three new chemical analyses are given. The upper and lower basalts are similar and closely comparable with the composition of the average basalt of the world. Richards says: "The basaltic rocks. . . . may represent outpourings of a comparatively undifferentiated primary basaltic magma. . . . . Gravitative differentiation may have gone on to some extent as the lower series is olivine free, while the upper series is rich in olivine (fayalite). . . . The intruded terrane almost certainly contains limestone, and the solution of this material to a small extent would be regarded by Daly as sufficient to result in the production of the phonolitic material from the calcic basic magma. . . . . The writer, however, in dealing with the origin of the volcanic rocks of south-eastern Queensland, regarded them as being differentiates of a single original magma."

RICHARDSON, W. ALFRED. "The Marginal Features of a Basic Dyke at Peldar Tor, Charnwood Forest," *Geol. Mag.*, LVIII (1921), 170–77.

A much altered greenstone (dolerite) dike which intrudes dacite shows a chilled marginal phase and a crystalline center. At the contact the margins are laminated, resembling columnar basalt, but actually consist of alternating sheets of country rock and dike. Three possible explanations for the lamination are given.

RICHARDSON, W. ALFRED. "A Method of Constructing Rock-Analysis Diagrams on a Statistical Basis," *Mineralog. Mag.*, XIX (1921), 130–36.

Diagrams for plotting the chemical analysis of a rock are given.

RICHARDSON, W. ALFRED. "A New Model Rotating-Stage Petrological Microscope." *Mineralog. Mag.*, XIX (1920), 96–98.

Describes a new Swift petrographic microscope.

RICHARZ, STEPHAN. "Die Basalte der Oberpfalz," *Zeitschr. d. deutsch. geol. Gesell.*, LXXII (1920), 1–100. Pl. 2, Figs. 8.

The basalts of the Oberpfalz are very similar megascopically, but under the miscroscope three types are recognized; pure nephelite-basalts, pure feldspar-basalts, and nephelite-bearing feldspar-basalts. No melilite-basalts were found although they occur at Steinberg near Hohenberg in Oberfranken. Some of the basalts are rich in both endogenic and exogenic inclusions, others rarely contain any. Among the inclusions are olivinefels, pyroxenites, fritted sandstones, and basalt-jaspis. In addition to the usual minerals, labradorite, nephelite, augite, olivine, magnetite, some glass, there occurs in some of these rocks, biotite. In the inclusions aegirite, katophorite, sanidine, oligoclase-andesine, quartz, and the recrystallization minerals, natrolite, phillipsite, calcite, aragonite, opal, and a new mineral called magnalite, occur. Field observations show that the basalt occurs in the form of dikes much more commonly than previously thought. The width varies from 50 to 200 meters.

RINNE, F. *Gesteinskunde*. Leipzig, 1921. 6th and 7th (double) ed., 8vo. Pp. 365, Figs. 510.

It is almost impossible in a short review to do justice to a general textbook which does not aim to present any startling new theories. One can do little more than give a summary of the table of contents. The first 120 pages of this book, which is not only a petrography but a petrology, are devoted to general geological modes of occurrence of igneous rocks, sediments, and crystalline schists, jointing, parting, and other structures, petrographic methods, and the mineral constituents of the rocks. The final 235 pages are devoted to descriptive petrography of igneous, metamorphic, and sedimentary rocks. As an introduction to the igneous rocks there are thirty-eight pages devoted to their chemical composition and modes of expressing these graphically, differentiation, gases in magmas, sequence of crystallization with many diagrams, and textures and structures. Following the general descriptions of the igneous rocks are a few pages on meteorites. Introducing the sedimentaries are sections on origin, weathering, transportation, deposition,

and diagenesis. Among the descriptions of the sediments, that on salt deposits is especially detailed, occupying sixteen pages. The crystalline schists are preceded by chapters on origin and textures. The book is profusely illustrated with photographs, undoubtedly excellent in the originals, but not well reproduced. The book may well serve as a text for students who have a sufficient command of German.

ROSENBUSCH-WÜLFING. *Mikroskopische Physiographie der Mineralien und Gesteine. Bd. I. Die petrographisch wichtigen Mineralien. Pt. I. Untersuchungsmethoden.* 5th ed., Stuttgart, 1921. Pp. 252, Figs. 192, and a colored plate.

This well-known work again has been revised, enlarged, and practically rewritten by Wülfing, so that it bears very little resemblance to the third edition of Rosenbusch. The present instalment of the book, which is the first half of the first part, all so far published, deals with methods of preparation, and with general theories of optics. Much new material has been added, and some of the old has been omitted to keep the size of the book within reasonable bounds, but how much has been omitted it is impossible to determine, in many cases, on account of the rearrangement and the appearance of only the first part as yet.

Following the Introduction, which is somewhat condensed, there is a section on preparation methods. The history of microscopical research, the description of stereographic projection, and the graphical methods and formulas, which followed in the fourth edition, are entirely omitted. Thirty-five pages on the preparation of thin sections come next, instead of being inserted between the chapters on optical principles and optical instruments, a decided improvement in arrangement. Here are given a number of new devices for cutting, grinding, and polishing. The cutting of oriented sections is described in considerable detail, occupying with the instructions for cutting plane surfaces and polishing, some fifteen pages.

Optical methods are introduced by a general discussion of theories of light. In the preceding edition, following the discussion of the indicatrices, the Fresnel ellipsoid, and uniaxial and biaxial ray and wave surfaces, came a section on lenses, microscopes, and various accessories. In the present edition this is omitted, probably to come later, and the discussion of optical phenomena continues unbroken. The same arrangement holds throughout the book. All of the theoretical material is brought together and the determinative methods are omitted, undoubtedly to be collected in the second half. This makes the different

parts of the book much more unified and gives a better appearance, but will it be so easy for the student?

After a discussion of interference phenomena there is a new section on the dispersion of birefringence and the departure of the interference colors of crystals from the pure colors of Newton's scale. Section 46, on the movement of light, has been entirely rewritten, and the figures have been redrawn. The material in this portion of the work has been so radically rearranged that it is difficult to compare it with the old edition, especially since some of the material may have been transferred to the future second part.

In the preceding edition, following the theoretical discussion of the intensity of transmitted light, came a chapter on the practical methods of determining extinction angles. In the new edition this is omitted, apparently to be given later, and the theoretical part is followed by an explanation of the phenomena in convergent light, and there are given the formulas for isochromatic curves, isogyres, and so on. The steps in obtaining Neumann's formula for calculating the values of birefringence in any section have been increased from a half to four pages, a very considerable help to the student who cannot refer to the original article. The section on interference figures also has been much extended, the explanation of the cross and rings obtained in uniaxial crystals alone having been increased from four and one-half to nine and one-half pages. Becke's skiodromes are given in illustration of both uniaxial and biaxial figures. Under dispersion the old cuts have been discarded and new and much better drawings, as well as photographs showing dispersion, have been inserted. The subject of pleochroism has been extended from twelve to sixteen pages, and a new section of two pages on luminescence has been added.

Polarizing prisms, which formerly came before the discussion of microscopes, and before the discussion of interference, pleochroism, etc., now comes near the end of the first half and takes up twenty-one pages. Finally, there is the concluding section on Monochromatic Light, increased from six to fourteen pages. Here are now given liquid color filters, more material on monochromatic flames and the monochromator, and a new description of the mercury lamp.

The book is now, as it has always been in the past, the one big indispensable work which begins where others end. Author and publisher are to be congratulated on its appearance. Press work, paper, and illustrations are excellent and, in spite of the difficulty of obtaining good paper, are fully up to the standard of previous editions.

SCHEURING, GEORG. "Die mineralogische Zusammensetzung der deutsch-südwest-afrikanischen Diamantsande," *Beiträge z. Geol. Erforsch. d. Deutschen Schutzgebiete*, Hf. I, 1914. Pp. 49, map 1, fig. 1.

Describes the minerals associated with the diamond in German Southwest Africa. Of petrographic interest from the description of a separating apparatus which might possibly be applied to the preliminary separation of rock constituents.

SCHLOSSMACHER, K. "Zur Erklärung der Becke'schen Linie," *Centralbl. f. Min. Geol.*, etc. (1914), 75–79, figs. 2.

A theoretical discussion of the Becke line. The writer shows that with vertical contacts the phenomenon is to be explained by Snell's law; with inclined contacts between minerals the effects are more complex, and may be accounted for in part by the explanation given by Grabham.

REVIEWS

The Problem of the St. Peter Sandstone. By CHARLES LAURENCE DAKE. Bulletin of School of Mines and Metallurgy, University of Missouri, Vol. 6, No. 1. Rolla, 1921. Pp. 228, pls. 30.

Professor Dake finds the St. Peter sandstone in Minnesota and Wisconsin equivalent to the upper part of the Chazy, and in Oklahoma and Arkansas, to all of it. It is unconformable with the Potsdam sandstone in Wisconsin, and with strata above the Potsdam farther south, up to the Arbuckle limestone in Oklahoma.

A study of the characteristics of the sandstone, such as composition, texture, and structural features was undertaken with a view to determining the origin of the sand. The author appears to have started with hospitable attitude toward the hypothesis that the sand is of eolian origin, but in the end he was led to the conclusion that several of the criteria usually held to indicate an eolian origin for sand (1) are "of less positive significance than is generally believed"; that (2) they are "significant only of conditions of transportation, and not of deposition"; that (3) they are "sometimes inherited from an older formation"; and that (4) they are "not present in the St. Peter in any appreciably greater perfection than in other sandstones of the same region known to be marine." He also holds that structural features imposed on a formation at the time it is laid down are "the only positive criteria as to conditions of deposition. These criteria point rather definitely to the marine origin of the [St. Peter] formation."

Of special significance in this connection is the basal conglomerate present in many places, for in it there is "no sign of wind polish or of faceted forms, and nothing comparable to desert varnish" (p. 187).

This conclusion as to the origin of the St. Peter sandstone is not only interesting in itself, but seems to suggest that the "continental deposition" idea, long neglected, has of late been overworked. In sundry recent publications it has almost seemed that if a marine origin for a formation is not proved, a non-marine origin is assumed. This volume is a wholesome check to this tendency.

Some of the author's detailed conclusions are as follows:

1. The composition and texture of a sandstone may furnish criteria regarding its derivation and transportation, but not regarding its method of deposition.

2. The history of the sand grains of a sandstone is usually so complex, including transportation successively by winds, streams, and waves, that textural criteria afford no proof whatever of the nature of transportation, even to the *last deposit in which the sand is found.* . . . .

3. The structural and stratigraphic relationships in the field, including such features as the character of bedding, cross-bedding, unconformities, lateral gradation and similar associated phenomena, constitute the only valid criteria for determining the conditions under which a deposit was last laid down, and these may sometimes give a clue to the method of transportation *to that particular resting place.*

4. The purity of the St. Peter sandstone, while very remarkable, as compared with that of average sandstones, is . . . . not sufficiently different from that of associated marine sandstones to demand any essentially different explanation of origin; . . . .

5. Size of train, *in pure quartz sands*, in general, is limited by the size of quartz grains in average igneous rocks, and is not a satisfactory criterion of wind-blown sands.

6. The size and uniformity of grain in the St. Peter is so near that of the Roubidoux marine sand, that no discriminations as to origin can be made on such a basis.

7. The degree of rounding and frosting of grains, which has been used as one of the chief arguments for eolian origin of the St. Peter, may often be masked by secondary quartz enlargement, but making due allowance for such modification, the St. Peter cannot be distinguished, on this basis, from the marine Roubidoux, or from older Cambrian sandstones. . . . .

8. The St. Peter shows bedding better developed than cross-bedding, and does not show typically developed dune-structure, even in the protected basal layers in the valleys of the old erosion surface. . . . .

11. Limestone layers occur at many horizons, particularly at the south, but are known as far north as north central Iowa and northern Illinois, and indicate marine deposition.

12. Oscillation ripple-marks in sand layers, marine fossils in limestone beds . . . . occur in Arkansas and Missouri, next above the unconformity [at the base of the series], showing submergence before the advance of the sand into the region.

13. Marine fossils are found in the St. Peter as far north as Minneapolis, not only in the uppermost transition layers, but also at three horizons, more than 60 feet below the top. These would not appear to have resulted from working over of dune deposits.

14–19. The St. Peter appears to have been derived from a relatively low land mass to the northward. This land is believed to have sloped southward, in which direction its rivers flowed, to have been affected by a moderately humid climate, but not to have been clothed with vegetation, because land plants had not yet developed. The land included pre-Cambrian crystalline rocks and a broad fringe of Potsdam sandstone.

20. The derivation of the St. Peter, largely from this Potsdam belt in which the sands were already well assorted and rounded, together with the added sorting and rounding by wind work in the supply area, and by waves in the sea, explains in a wholly satisfactory manner the high degree of purity and rounding of its grains.

21. These sands were delivered to the sea both by rivers and to a minor degree directly by winds, and were distributed chiefly by waves and currents.

22. The shores of this sea were fluctuating, but during middle and late St. Peter time, were for the most part north of the Iowa-Minnesota line.

23. North of that line there is quite probably a small amount of St. Peter that is truly unmodified terrestrial deposit. . . .

24. South of the Iowa-Minnesota line, conditions of both transportation and deposition were almost wholly marine, and in this area there did not exist during any part of St. Peter time, a great interior desert of drifting sand.

A discussion of the geographic conditions under which this and other early Proterozoic formations were made, closes the volume.

R. D. S.

Deposits of Manganese Ore in Arizona. By E. L. JONES, JR., and F. L. RANSOME. Bulletin 710-D, United States Geological Survey, Government Printing Office, Washington, D.C., 1920. Pp. 92, pls. 6, figs. 8.

The production of manganese ore as such in Arizona dates from 1915. The producing district lies in the more southern part of the state. The greater part of the ore worked bears at least 35 per cent manganese, and not more than 4 per cent iron. The ore is shipped east to Illinois, Alabama, Tennessee, and Pennsylvania, and lately also to California. Perhaps the chief difficulty encountered in production lies in the inaccessibility of the mines to railroads, which necessitates "packing" the manganese out of the mining district, a tedious and expensive process.

Various scattered manganese have been studied by Mr. Jones in the preparation of this paper. Dr. Ransome describes those at Bisbee and Tombstone. In the latter district, the sequence extends from the pre-Cambrian Pinal schist through Cambrian, Devonian, Mississippian,

Pennsylvanian, Triassic (or Jurassic), and Comanchean rocks. These are mostly limestones, though the early Mesozoic is marked by porphyritic intrusions and the lower part of the Cambrian series is quartzitic. The manganese ore, largely psilomelane, occurs in irregular bodies in close association with fissures in the Carboniferous limestones; the deposits follow the fissures, or extend laterally from them along certain beds of limestone; they seldom descend to depths greater than fifty feet and are worked by open cuts or shallow inclines. With the hard psilomelane are lesser amounts of barite, quartz, a green copper-arsenic compound (new species), and soft black pyrolusite; chalcolite is occasional.

In the Tombstone district the manganese grades into ores rich in the precious metals; it occurs in irregular pipelike masses or chimneys distributed along fault zones.

Almost certainly these manganese deposits are related to the copper ores, as they are generally closely associated. The manganese ores are unquestionably supergene, being generally found only in the oxidized zone. Psilomelane deposition seems to have been conditioned chiefly by fissuring. In the Tombstone district, manganese-silver ores are as common as manganese-copper ores in the Bisbee region, and possibly the manganese zone here represents a leached silver zone. The deposits, on account of their irregularity, can only be worked under unusual conditions. Possibly not more than 60,000 tons of 40 per cent ore are available in these two districts combined.

Elsewhere in the state, in Coconino, Graham, Greenlee, Maricopa, Mohave, Pinal, Santa Cruz, Yavapai, and Yuma counties, there are smaller manganese deposits. Here veins, brecciated zones, bedded deposits, and irregular deposits with travertine, all furnish greater or lesser amounts of manganese ores. The ores are in pre-Cambrian granites and gneisses, Tertiary rhyolites, andesites, and dacites, and Quaternary basalts, as well as in limestones and quartzites of Paleozoic age, sandstones of Tertiary age and course clastics of the Quaternary. The manganiferous silver veins occupy an important place among the vein deposits; they are well shown in the Hartshell shear zone ores and in the Globe district; in such cases the manganese oxides are psilomelane, pyrolusite, braunite, manganite, and wad. There may be more or less iron oxide associated, as in the Globe district, where the ores are intimate mixtures of manganese- and iron-oxides. Where braunite is the chief ore mineral, it is commonly associated with cerusite, vanadinite, and wulfenite.

Veins barren of silver are widely scattered throughout the southern part of the state and include most of the deposits examined. They are most common in Tertiary lavas. The ore-shoots vary greatly in size. The ore consists of oxides derived from the weathering of vein material, hence its depth depends largely on the permeability of the rock to circulating water. The ore minerals are psilomelane, pyrolusite, and manganite; these are accompanied by barite, calcite, and iron oxide.

Bedded deposits vary as to character and associated rocks. They may be contained in tuffs, or they may be the result of replacement of sandstone. They are generally of Tertiary age. Such deposits do not extend to great depths and are worked through shallow pits and shafts. The manganese minerals are psilomelane, pyrolusite, manganite, and subordinately braunite. Quartz, feldspar, iron ores, and calcite are the chief gangue minerals—partly secondary, partly the unreplaced minerals of the rock. Much of this ore, developed in sandstones and only partially replacing the country rock, is siliceous.

Manganese ore associated with travertine is known from one locality only; here the travertine and the clayey manganese-bearing beds are capped by basalt. The manganese mineral is principally botryoidal and vesicular psilomelane.

A detailed description of the geography, geology, and manganese deposits of each of the districts is given; for these the reader is referred directly to the carefully prepared paper itself.

C. H. B., Jr.

World Atlas of Commercial Geology; Part I, Distribution of Mineral Production. United States Geological Survey, 1921. Pp. 72, pls. 72.

The purpose of this atlas, prepared by more than a score of geologists, is "to set forth graphically and to describe concisely the basic facts concerning both the present and the future sources of the useful minerals." Part I deals chiefly with present sources; later parts will exhibit, so far as practicable, the mineral reserves of the world. The maps of Part I, which deal with the most important thirty mineral commodities, are arranged in groups of eight, each group containing (1) a map of the world showing production and, for major commodities, consumption by countries in 1913, the last year of normal production; (2) a map of each of the continents, indicating production by countries, districts, or fields, in percentages of the world's production in 1913; and (3) a map of the United States, exhibiting production in 1918 by states, districts, or fields, in percentages of the total output of the country.

The accompanying text presents briefly and effectively fundamental facts concerning the various minerals, under headings such as uses, geologic occurrence, geographic distribution, technology, centers of consumption, and the like.

The atlas is an outgrowth of investigations of mineral problems begun during the war, investigations of a type too long delayed in this country, for the facts concerning the distribution, quality and quantity, availability, and commercial and political control of the world's mineral resources are destined to affect increasingly our trade and industries and our relations with other peoples.

HARLAN H. BARROWS

An Introduction to Paleontology. By A. MORLEY DAVIES. London: Thos. Murby & Co.; New York: D. Van Nostrand & Co.

Mr. Davies has planned his book with the intention of making it, above all else, a practical, usable textbook for courses in the elements of paleontology. To this end, he begins with those animals which are most common as fossils, and which can be studied most easily by the beginner—the Brachiopoda. He first describes certain common species, in order to give the student a clear idea of the general characters of the group, and then presents a brief, but tolerably adequate, account of the entire class.

From the Brachiopoda the author carries his text along the ascending scale, through the vertebrates. He then returns, begins with the Echinodermata, and follows the descending order, finishing with the Protozoa. The system of treatment violates tradition, and certainly has the disadvantage of leaving a beginning student in something of a muddle as regards classification. But it has the advantage of beginning with the easy, and proceeding to the difficult, and parallels the system of treatment used in several of the more recent and progressive high-school texts in zoölogy.

On the other hand, Mr. Davies has adopted a few innovations that are neither advantageous nor, so far as can be seen, justifiable. There is no clear ground for separating the Molluscoidea into two groups, and putting the Bryozoa with the corals; neither is it plain why the Pythonomorpha have been omitted entirely, and the Aves reduced to an order among the Reptilia. These are points that an instructor may correct, but it is not clear why he should be forced to do so.

C. L. F.

The Mineral Resources of the Philippine Islands for the Years 1917 and 1918. Contributors: ELMER D. MERRILL, VICTORIANO ELICANO, LEOPOLDO A. FAUSTINO, W. H. OVERBECK, and T. DAR JUAN. Issued by the Division of Mines, Bureau of Science, Bureau of Printing, Government of the Philippine Islands, Manila, 1920. Pp. 75, pls. 8, tables 12, and analyses.

This issue of *Mineral Resources of the Philippine Islands* deals with the years 1917–18, following the plan expressed in the first issue of 1908, which was continued by annual publications until 1916. Of great interest in the publication under review is the increase in the importance of coal, the slump in gold mining, the appearance of asbestos as a mineral product of the Islands, and the discovery of more deposits of iron. Lesser resources treated are sulphur, manganese, and asphalt. The gold production in 1917 was about 1,990,000 grams; in 1918 it was about 50,000 units less. Silver production increased from 81,000 odd fine grams in 1917 to 128,000-odd in 1918. A still greater advance is recorded in the coal production—from 5,000 tons (round numbers) in 1917, to 15,000 tons in 1918. Since the year 1907 there has been a steady increase in mineral yield except in 1910.

In spite of the increasing gold production of the Islands, it must be admitted that gold mining is still in the formative stage. The largest production comes from Masbate and the Mountain Provinces, and the largest single mine is the Benguet Consolidated Mining Company, in the Mountain Province district.

Three sources of iron ore have been exploited in the islands, and magnetite sand, briquetted, is also being experimented with. Lead and zinc deposits in Marinduque Island are described. They are fissure veins, 4 to 10 feet wide, running as high as 60 per cent lead or 45 per cent zinc; the minerals are galena and sphalerite, the gangue is quarts, and the country rock andesite. Manganese has been produced to some slight extent, and copper is mined in Mancayan.

Most Philippine coal is really lignite, but good bituminous coal is known from Polillo Island and in the Zamboango district. At the close of 1918 twenty-three mines were producing coal. In the better mines a modified room and pillar method is used, the room being also an entry. Considerable waste, especially on the part of small operators, is the rule. Mine gases are rare, the walls are good, and ventilation problems in these shallow mines are simple; transportation, however, is a real difficulty in coal mining. An interesting feature of coal production is the development of producer gas plants on the Islands.

Asbestos manufacture is a new industry in the Philippines. At present only one district—that of Ilocos Norte—is productive. Both amphibole and chrysotile asbestos are known. An asbestos plant is now operating in Manila.

Oil exploration is so far merely preliminary and confined to the Lake Lanao-Cotabato district (Mindanao) and to the Tayabas field. The Mindanao oils have a specific gravity of .93 to .91 as analyzed; the base is paraffin.

Sulphur is found in solfataras and in the impure state, mixed with volcanic ash, in several localities. The production of cement has virtually ceased because of the failure of the largest cement plant. Fire-clay, lime, sand and gravel, stone, salt, and mineral and artesian waters are the other resources treated. A separate chapter is devoted to glass-making; this demonstrates the accessibility of all the material necessary to the process—lime, silica, and alkali.

The report urges the revision of the federal mining laws and the establishment of a school of mines. The adoption of a leasehold system is advocated; present mining law in the Philippines requires that 200 pesos worth of development be performed annually on located, unpatented claims, which "does not always accomplish the purpose sought either by the Government or the claim holder."

The report contains a directory of mine-owners, lessees, and operators, and a transcript of the mining laws of the Philippine Islands. Several good photographs accompany the report, but unfortunately others are carelessly mounted—possibly the error of the publisher—and still others show little or nothing of the very features they are presumed to illustrate. Some of these shortcomings may no doubt be laid at the door of the smallness of the funds available, which has compelled a reduced staff to disperse its energies over a large field. Similarly, no doubt, the general lack of detailed geological descriptions may be accounted for. All in all, the report is of distinct value.

C. H. B., Jr.

Deposits of Manganese Ore in Costa Rica and Panama. By Julian D. Sears. Bulletin 710-C, United States Geological Survey, Government Printing Office, Washington, D.C., 1919. Pp. 31, pls. 1, figs. 28.

This bulletin is actually two separate papers—one dealing with the manganese of Costa Rica, the other with that of Panama.

The known manganese deposits of Costa Rica are all in the Province of Guanacaste, on the Pacific Coast. They are widespread, but generally

either of low grade or of small extent. Only two really important deposits are worked.

The important manganese deposits of Costa Rica are in the Nicoya Peninsula, which is very hilly, with a "backbone" running in a generally northwesterly direction. The east coast (Nicoya Gulf) is low, with swamps and estuaries, while the Pacific coast is high and rugged. The rocks are chiefly sandstone, shale, conglomerate, and limestone. Most of the sediments have undergone considerable dynamo-metamorphism, the greater part being now iron-pigmented quartzite, but other less highly colored quartzite occurs higher in the sequence. Silicified limestone, shale, and breccia are also reported. Igneous rocks include basic fine-grained types, largely flows (?). Some intrusions are also thought to characterize the region though no plutonic rocks are actually described. Structurally the area seems to indicate an igneous basement, with superjacent sediments that have been intricately folded and faulted since deposition.

The ore-bodies are manganese oxides, partly soft (pyrolusite?), partly hard and crystalline. Iron oxide is generally low, but silica occurs mechanically admixed. The oxides are found in pockets or troughs between the red metamorphosed rocks and lighter colored sediments, or may be in direct contact with igneous rock. Generally the deposits are too small to merit another term than "pocket," but they may be as large as 500 by 100 feet, averaging 5 feet in thickness. The exact size of these ore-bodies is not determinable, and estimates of a reserve based on a 40–45 per cent ore are therefore not dependable.

The ores are related to fault zones but not all the faults of the region are ore-bearing. The ore is attributed by the writer to hydrothermal action, the hot, ascending solutions passing along the faults and spreading on planes of contact between formations and depositing the manganese as a carbonate or silicate which was later oxidized. The great silicification of the wall rock and close relation between the ore and fissures are supposed to lend credence to this view. On the other hand the manganese may be the product of downward concentration, deposited because of the impermeability of the highly metamorphosed rocks.

A detailed discussion of the mines and prospects emphasizes their economic insignificance. Two only are of importance as producers at present, those at Playa Real and at Curiol, and one prospect (Pavones) may prove to be productive in the future.

In Panama two manganese deposits are known on the west side of the Boqueron River, about 20 miles east of Colon. The country near

the mines is hilly, and in places reaches altitudes of 1,000 feet. The rock immediately adjacent to the deposits is fine-grained sediment containing much siliceous cement, or hard, gray, siliceous limestone. Associated with the ore-bodies are shales and breccias, and a dark igneous rock, probably basalt.

At Mine No. 1, the manganese occurs as mixed oxides, largely in bowlders, or segregated in lenses and sheets in varicolored clays. The manganese ore may be in stringers or beds in the clay. It appears to be the result of concentration and segregation. Taking all the possible sources of manganese together, about 10,000 tons are available at this locality.

At Mine No. 2 the ore is also in bowlders, which lie on the surface, or in clay banks; here too are sheets of manganese ore, ranging in thickness to 15 feet. Manganese is also segregated in a zone in bedded breccia, formed apparently through concentration in the residual clays that weathered from the breccia.

In general, therefore, the manganese ores appear to be residual, not unlike those of the Piedmont district of southeastern United States.

C. H. B., Jr.

The Iron and Associated Industries of Lorraine, the Sarre District, Luxemburg, and Belgium. By Alfred H. Brooks and Morris F. LaCroix. United States Geological Survey, Bulletin 703, 1920. Government Printing Office, Washington, D.C. Pp. 131, pls. 2, figs. 12, and numerous tables, including statistics on Belgian iron and coal production.

This report was prepared at Paris for the use of the American Commission to Negotiate Peace. It illustrates again the value of geology in fields normally considered foreign to the science. It calls to mind too the desirability of making peace-terms on the basis of such carefully organized facts with a view to stabilizing world-industry, rather than on the principle that to the victor belong the spoils.

The purpose of the original report was to lay before the commission certain facts relating to the pre-war use of Lorraine iron ore and thereby to forecast the probable future of the metallurgical industry in Lorraine as modified by the new national control which were under discussion when the report was submitted. . . . . The original report was in effect an argument for the adoption of certain policies with reference to the iron and coal industries of central Europe. . . . . For these reasons the reader will find that certain parts of the report are presented as arguments rather than as expositions.

The importance of the iron ores of Lorraine Annexee and French Lorraine may be shown by the fact that they furnished in 1913 34 per cent of the total iron consumed in Europe.

Lorraine Annexee, that part which Germany controlled subsequent to 1872, produced in 1913 75 per cent of the entire German output of iron ore. The reserves aggregated about 1,830,000,000 tons of ore averaging about 30 per cent iron. More than two-thirds of the coke used in Lorraine Annexee came from the Westphalian and Aix-la-Chapelle districts; the remainder, only some 1,500,000 tons, was from the nearby Sarre field. The European iron reserves in other fields were being rapidly depleted, and it would thus have been greatly to the interest of Germany to obtain control also of the French Lorraine field. German capital already owned 10 to 15 per cent of the entire iron district by purchase before the outbreak of the war, and if French Lorraine had been annexed, Germany would have controlled 50 per cent of Europe's iron resources. As it is, however, "the Treaty of Versailles has left Germany with only 7 per cent of Europe's iron reserves, while France owns 48 per cent. Moreover, the deposits of iron ore in the German Republic are widely scattered, and some of them are not favorably located for economic development. Therefore any large production of iron and steel in Germany must be based on imported ores." Only her Westphalian coking coals prevent the immediate annihilation of Germany's metallurgical industry; this coal, it is shown in the report, is necessary to assure the economic utilization of France's Lorraine ores.

In general the iron deposits of Lorraine occur in a belt extending northward from Metz along the pre-war frontier between France and Germany in an area averaging 60 kilometers long and 20 kilometers wide. The more southerly Nancy iron district lies entirely within the pre-war French territory and forms an outlier of the main field. The dip of the beds is gently westward, though modified by slight folds and faults.

The ores are mined at a low cost; this, taken with their great extent, their proximity to coal fields and markets, and their composition, which adapts them to the basic process, gives them their great value. The phosphorus content is 1.5 to 2 per cent, fairly constant, and yields valuable slag fertilizer. The iron mines in the occupied parts of Lorraine were but little damaged by the Germans, but the furnaces, which might later be expected to compete with German ones, were injured or destroyed.

About 74 per cent of all coking coal that is sufficiently near for economic use in Lorraine lies in the Westphalian fields of Germany.

The Sarre fields can only contribute some 22 per cent of the needed coal, so that with the restoration of Lorraine Annexee, France holds much smaller coal reserves than either Germany or Great Britain.

In the Westphalian field of Germany the coal is close to tidewater and is connected by rail and by waterways with the iron and steel centers of Lorraine and Belgium. The district produces about half of the total German output of pig iron, and in 1913 some 45 millions of tons of Lorraine ore were smelted there. About 180 coal mines are operated. The Sarre coals lie near the Lorraine field—some thirty kilometers east—but are far inferior in coking qualities to those of Westphalia. There are from 27 to 32 workable seams, aggregating about 40 meters in thickness. The total reserve, estimated to a depth of 2000 meters, is about 16 million tons. The coal cokes but poorly, yielding on the average 50 per cent coke; in blast furnace practice, therefore, it is customary to make the charge of equal quantities of Sarre and Westphalian fuel. The Sarre coal is really best used for steam, gas, and domestic purposes.

There are no large coal reserves in Belgium, excepting possibly in the Campine Basin. The Campine coals, after development has proceeded a little further, may, with the Sarre, supply enough coal for all the Lorraine ores; but in an open market, they could not compete successfully with the higher grade Westphalian coal.

Luxemburg bears reserves of iron that should last about thirty-five years. It supports large furnaces; there were in 1913, forty-six blast furnaces and six steel plants. Of the six large corporations that control most of the stock, four are German, one Belgian, and one mixed capital.

The entire compilation is to be commended, first for its purpose —the application of economic facts to international problems—and second for its accuracy and completeness. Two good maps illustrate the geographic relations of the coal and iron districts in question; many graphs, tables, and diagrams make the salient points doubly clear.

C. H. B., Jr.

The Earlier Mesozoic Floras of New Zealand. By E. A. Newell Arber, M.A., Sc.D., F.G.S., F.L.S. Wellington: New Zealand Geological Survey, Palaeontological Bulletin No. 6, 1917. Pp. 72, pls. 14.

This memoir is concerned with an account of the earlier Mesozoic floras of New Zealand, with which very little work has hitherto been attempted. A majority of the species described are new. One result

of the work has been to show that, despite assertions to the contrary, no trace of any Paleozoic flora has been found in these islands. Rumors of the presence of Glossopteris-bearing rocks have no foundation in the material studied. Even in Permo-Carboniferous times, when the southern continent of Gondwanaland included a large part of the Southern Hemisphere, New Zealand did not, on the basis of the known evidence, form any part of that continent. Whether beds of Permo-Carboniferous age do or do not occur, is not definitely known.

So far as may be concluded from present evidence, the Mesozoic land connections between Antarctica and the temperate regions of the Southern Hemisphere appear to have been chiefly in the direction of New Zealand and Australia. Although somewhat similar Wealden floras are known in South America, the evidence is too meager to warrant conclusions concerning its connection with other southern lands.

The portion of the paper devoted to systematic paleobotany includes the description of forty-eight species, all of which are figured. The report includes an extensive bibliography.

A. C. McF.

ERRATA

Journal of Geology, Vol. XXX, p. 269, footnote, line 2, "Oct., 1922" should read "*Sept.*, 1922."

P. 269, footnote, line 8, "pp. 36" should read "*Vol.* 36."

P. 286, footnote 1, should read "Cf. footnote 3 on page 270."